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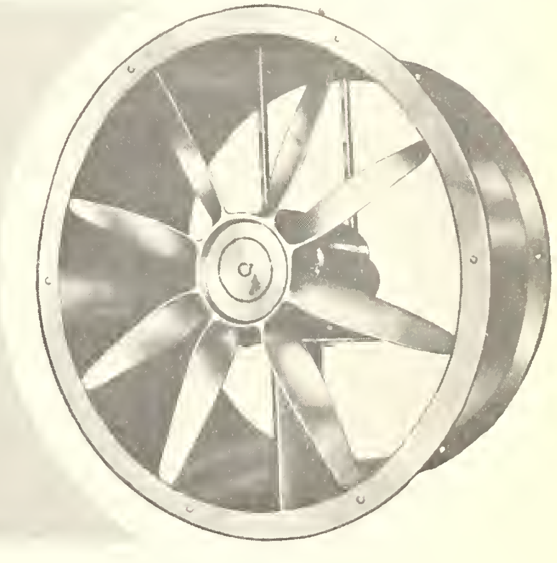
MARKETING RESEARCH REPORT No. 481

AERATION OF BULK-STORED PEA BEANS



UNITED STATES DEPARTMENT OF AGRICULURE
Agricultural Marketing Service
Transportation & Facilities Research Division
in cooperation with
Michigan Agricultural Experiment Station

PREFACE

This report is based on the results of research on the aeration of dry pea beans in commercial storages, conducted in cooperation with the Department of Agricultural Engineering, Michigan Agricultural Experiment Station. The study is part of a broad program of research aimed at improving the efficiency of marketing farm products. Some of the information reported is closely allied to certain information contained in Marketing Research Report No. 178, "Aeration of Grain in Commercial Storages," revised in 1960.

The work was conducted under the supervision of Leo E. Holman, agricultural engineer, Agricultural Marketing Service, who also assisted in assembling and preparing material for the report. M. S. Sefcovic, food technologist, Agricultural Marketing Service, provided information for use in the report.

Acknowledgment is made of the cooperation and assistance given by individuals and organizations in the pea bean industry and by suppliers of aeration equipment in making this research possible.

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June 1961

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SUMMARY

New methods of harvesting and handling pea beans have brought about the use of larger bulk storages. Handling and storage costs can be reduced with larger storages, but maintaining the quality of the beans stored in them becomes a problem. The control of undesirable moisture accumulations in the surface layers of beans is probably the most important problem. Beans can be "turned," or moved, from one storage to another to prevent moisture accumulation or to equalize moisture in beans. Turning is undesirable, however, as the beans may crack or split during the turning. Also, extra storage space must be available for turning, and the beans are difficult to move if stored in a flat storage.

Research in the Michigan area in 1955-59 provides good evidence that aeration is an effective and desirable means of controlling moisture accumulation and of maintaining the market quality of beans stored in bulk. Aeration is applicable to all types of storages, including flat storages where turning is difficult. There is also evidence that proper aeration can prolong safe storage and remove undesirable odors.

Research results indicate that an airflow rate of 1/10 cubic foot of air per minute (cfm) per bushel is practical and satisfactory for upright and flat storages; also, that rates as high as 1/5 cfm per bushel are feasible in flat storages where air distribution is more uneven and static pressures lower than in upright storages.

Either axial flow (propeller) fans or radial flow (centrigufal) fans can be used in aeration systems where the total static pressure is not much greater than 4 inches of water. Centrifugal fans generally are used where pressures exceed 4 inches.

Several fan arrangements may be used: A fan for each storage or duct, a single fan connected to several storages or ducts, or a single portable fan moved from storage to storage or from duct to duct.

The design of the ducts (to be placed in the beans) into which air from the stored beans is drawn is as important as any part of the aeration system. The important dimensions of the ducts are the cross-sectional area, the length, the surface area, and their spacing. The cross-sectional area required is directly related to the duct length and the volume of air carried. Ducts should have sufficient surface area--circumference or perimeter--so that the velocity of the air moving through the beans surrounding the duct will be around 20 to 30 feet per minute (fpm) and never over 50 fpm. It is recommended that, with level loading, the space between the ducts should not greatly exceed the depth of the beans.

Aeration fans can be controlled (1) manually or (2) automatically by the use of temperature-sensitive switches (thermostats) and humidity-sensitive switches (humidistats). Automatic controls are desirable to insure aeration whenever weather conditions are suitable.

Four years of research demonstrated that fans automatically controlled to operate when the temperature is between 32° and 45° F. and relative humidity is below 80 percent provide adequate aeration of pea beans in the Michigan area.

Generally, air is drawn downward through stored beans to prevent moisture accumulation in the upper surface layers. During aeration, a cooling layer or "zone" moves through the beans. The beans below the zone remain uncooled while those above are cooled to near the outside air temperature. A cooling zone should be moved completely through the beans before aeration is stopped, to prevent moisture migration from warm to cool beans which may cause "hot spots" and spoilage.

At 1/10 cubic foot of air per minute per bushel about 150 hours of fan operation are required to cool the beans to near the average outside air temperature existing during the aeration period. Flat storages may require more time because here airflow is not as uniform as in upright storages.

The cost of aerating bulk-stored beans will vary with the type and size of storage, the type of aeration system, the airflow rate selected, and the amount of aeration per lot of beans. In the two examples included in the report the annual ownership and operating costs were calculated to be 0.66 cent per bushel for a multiple bin (upright) system with a permanently placed single fan and the required supply pipes, and 0.75 cent per bushel for a flat storage, level loaded, with one fan and two floor ducts installed lengthwise of the storage. These costs will vary upward or downward, depending upon any variations in the systems described and in the number of hours of fan operation per year.

AERATION OF BULK-STORED PEA BEANS

By John S. Perry, agricultural engineer,
Transportation and Facilities Research Division,
Agricultural Marketing Service 1/

BACKGROUND

During recent years the methods of harvesting and handling pea beans have undergone gradual changes. Stacking and the use of stationary threshing machines have been almost completely replaced by pulling, windrowing, and using combines. 2/

Timeliness in harvesting is particularly important when using combines, as pea beans in windrows can deteriorate quickly under adverse weather conditions. With the increased use of combines, pea beans are harvested over a relatively short period and seem to vary more in moisture content and storage condition. Thus, pea beans move to market in shorter periods and are received in somewhat poorer condition for storage.

To adjust to these changes, more and larger bulk commercial storages are being used. To establish a satisfactory basis for payment, pea beans are cleaned when they are received from the grower. The beans are then stored in bulk, usually in bins, silos, or flat storages of various types. Later the beans are recleaned, sorted, bagged, and graded in preparation for sale and shipment to retailers or canners. The beans go into bulk storage in October or November and remain in storage until it is convenient to process them for sale. It has been estimated by those familiar with the bean industry that the bulk storage capacity doubled in Michigan during 1958 and 1959.

Problems of Storing Pea Beans

The moisture content of pea beans is the most important consideration in their storage. When the moisture content is above 18 percent, molds and a musty odor may develop.

During harvesting and movement into storage, pea beans are effectively inoculated with a variety of mold spores both from the soil and from the dust normally found in elevators and warehouses. Apparently there are many kinds of molds that cause spoilage in storage, and research work is in progress to identify the types involved and the process by which spoilage occurs. Mold growth occurs over a wide range of moisture and temperature conditions and usually is accompanied by a musty odor. Mustiness can indicate mold growth before it is visible to the unaided eye.

1/ Mr. Perry is now associate professor, agricultural engineering department, University of Massachusetts.

2/ McColly, H. F. Harvesting Edible Beans in Michigan. Amer. Soc. Agr. Engin. Trans., v. 1, No. 1, pp. 68-71, 75. 1958.

Mold growth in stored pea beans of normal moisture content (below 18 percent) and at moderate storage temperatures (below 60° F.) usually is slow. If moisture accumulates in localized areas in the stored beans, mold may develop rapidly, though temperatures are as low as 40° F. Aeration offers a method of controlling mold growth in storage by preventing localized increases in moisture and by reducing temperatures of the stored beans below the optimum for mold growth.

When the moisture content of beans is below 12 percent, excessive splitting and checking of seed coats may occur when the beans are handled. Temperature of the beans is also a factor affecting splitting and checking. Splitting and checking increase as the temperature and moisture of the beans decrease. Grade requirements establish a definite limit as to permissible splits, and beans with checked seed coats will split more easily than beans with sound seed coats. Checked seed coats detract from the appearance of packaged dry beans, and the detached and curled seed coats which often show up in the canned beans are unattractive. Factors other than moisture and temperature also affect splitting and the formation of checked seed coats. The weather conditions to which the beans have been subjected and the mechanical treatment the beans have previously received are apparently important.

Disadvantages and Limitations of Turning Beans

A customary method of preventing deterioration of bulk-stored beans is to turn, or move, the beans from one storage to another. A mixing occurs, and beans of various temperatures and moistures are more uniformly distributed. Beans with a high moisture content are mixed with drier beans. The more uniform temperature of the beans temporarily prevents convection currents and accumulation of surface moisture.

There are disadvantages to turning, as beans tend to develop checked seed coats and splits when handled. Losses can be serious, particularly if the temperature and moisture content of the beans are low. Since storage space must be available for the beans that are to be turned, not all storage space can be completely utilized. Turning is difficult in flat storages because considerable labor and equipment are needed. Additional depreciation, maintenance, and power costs of equipment are other items that are involved in the cost of turning. Experience indicates that operating costs for turning may vary from 1/10 to 1/2 cent per bushel each time beans are turned. The total annual cost of turning beans also includes equipment and ownership costs, losses due to checked seed coats and splits occuring during turning, and the loss of revenue from storage space held for turning. Costs will vary with the type of storage and the equipment available.

Another practice commonly used to minimize storage losses is the removal of the top layer of beans when the moisture content of this layer becomes high. This "scalping" of a storage is a temporary measure. The temperature distribution within the bean bulk, which causes convection currents and accumulation of moisture at the top, remains undisturbed. Under such conditions moisture will continue to accumulate in the beans near the upper surface without interruption.

Aeration

For years grain storage operators have been aware that moisture may accumulate in the upper surface layers of bulk-stored grain. This accumulation usually starts in the fall and winter when cold weather arrives. It is usually more severe in colder climates. Not until early 1940 was it shown that these accumulations were mainly caused by moisture migration. [3] Convection air currents move within the stored grain bulk when the weather turns cold. Air near the walls is cooled and settles and this causes the warmer air in the center of the storage to rise. Some of the moisture in this warmer air is absorbed by the cooler grain in the surface layers. Thus, moisture in the surface layers may increase and result in storage losses.

Aeration is being successfully used to prevent convection air currents in bulk-stored grain and moisture accumulation in the surface layers. The term aeration refers to the practice of moving air through stored grain at low airflow rates, for purposes other than drying, to maintain or improve its value. The principal value of aeration in the bulk storage of pea beans is in cooling and equalizing bean temperatures so that moisture does not accumulate in the beans near the upper surface. Pea beans develop a characteristic "beany" odor in storage, and observation has shown that this odor can be reduced by aeration, though there is no assurance that such reduction is permanent. Often fumigation, if required, can be carried out with an aeration system. It is sometimes feasible to hold damp beans for brief periods if aeration is available This may be of considerable importance in meeting processing schedules. Aeration is sometimes used to cool grain that has been recently dried. For this purpose, aeration equipment installed in an easily accessible temporary storage is frequently convenient. It is logical to expect that stored beans will maintain a better color when cool, and they can be cool through the use of aeration.

Purpose and Scope of Studies

In early 1955 studies were started in the pea bean producing areas of Michigan to determine if aeration could be used effectively to help insure the safe storage of pea beans.

Normally, pea beans are harvested in Michigan through September and October. Large quantities of beans are received at country elevators at harvest time and are stored in bulk. These elevators specialize in the storing, cleaning, sorting, grading, and wholesaling of beans. These marketing processes begin after harvest and continue throughout the winter and into the following spring and summer.

So, it is necessary to store beans in bulk throughout the winter and into the spring or early summer until they can be processed for sale. However, spoilage sometimes occurs because of accumulation of moisture in the surface layers of beans and because of localized heating, commonly referred to as

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[3] Holman, Leo E. Aeration of Stored Grain. Agr. Engin. Jour. 36: 667, 668, 672. 1955.

"hot spots," in the bean mass. In the larger bulk storages these losses cannot be avoided easily by turning or scalping the beans.

A series of aeration studies was undertaken in Michigan to establish whether hot spots and moisture accumulation in surface layers of stored beans could be prevented by aeration; to determine adequate airflow rates and the requirements for fans, duct designs, and fan control systems; to develop satisfactory operating practices and methods; to determine costs of ownership and operation; and to learn the limitations of aerating stored pea beans.

Equipment and Facilities Used in Tests

The studies were made at several locations with the following types of facilities and equipment:

Flat storage.--40 feet wide by 100 feet long with a capacity of 40,000 bushels (fig. 1). A central floor duct, extending lengthwise through the storage was used, and a 1-horsepower motor and fan supplied air at an estimated rate of 1/10 to 1/15 cubic foot of air per minute (cfm) per bushel. The fan was manually started and stopped.

Flat storage.--50 feet wide by 120 feet long with a capacity of 60,000 bushels (fig. 2). Two different arrangements of floor ducts were used: In half of the storage, two ducts were installed lengthwise; in the other half, three ducts were installed crosswise. Each duct arrangement (half of the storage) was equipped with a 1-1/2-horsepower motor and fan controlled by two thermostats and a humidistat connected in series. The airflow was estimated to be about 1/5 cfm per bushel for each fan.

Upright storage.--A typical small country elevator or bean receiving station, 30 feet square by 50 feet high, containing 15 bins. Each bin was approximately 9-1/2 by 9-1/2 feet and 24 feet deep, with a sloping bottom, and a capacity of about 1,800 bushels (fig. 3). A floor duct was installed in the test bin, and air was supplied by a 1/4-horsepower motor and fan. The estimated airflow rate was 1/10 cfm per bushel. The operation of the fan was controlled by a high-limit and a low-limit thermostat and a humidistat. A check bin with no aeration was provided for comparison.

Upright storage.--One elevator consisting of 10 concrete stave silos or tanks, each tank 32 feet in diameter and 60 feet high, holding approximately 35,000 bushels of pea beans (fig. 4). The two test tanks were equipped with floor ducts, and a 5-horsepower motor and fan were used to supply air at a rate of about 1/10 cfm per bushel for one tank and at 1/30 cfm per bushel for the other. The operation of the fan was controlled by two thermostats and a humidistat. An unaerated tank was used as a check bin for comparison.

All four test storages listed above were equipped with thermocouple cables to compare bean temperature patterns in aerated and unaerated storages and to determine the effectiveness of aeration in maintaining suitable temperatures of stored beans. Moisture in the bean mass was determined from samples taken with conventional grain probes. Moisture accumulation in the

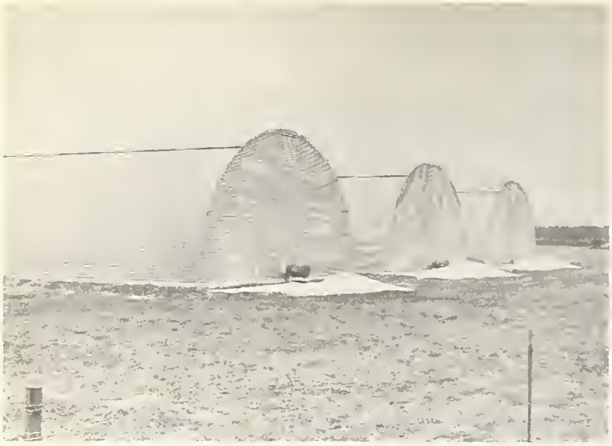

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Figure 1.--Flat metal storages, each 100 feet long by 40 feet wide and each aerated with a single fan and motor unit.

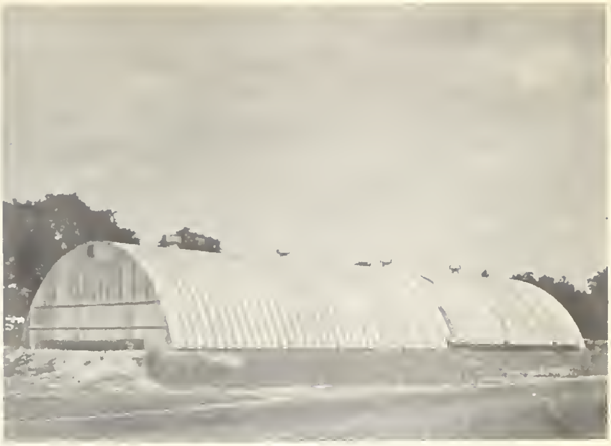

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Figure 2.--Flat metal storage 120 feet long by 50 feet wide. Supply pipe along end of the building connects two aeration ducts extending lengthwise through the storage. Supply pipe along side of building connects three ducts extending crosswise through the storage.

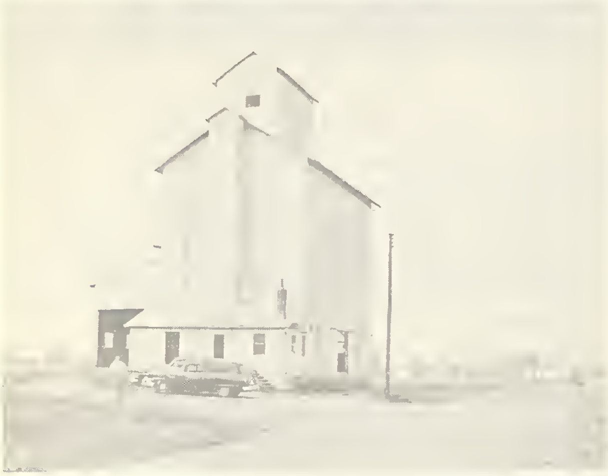

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Figure 3.--Country elevator used for receiving and storing pea beans. Two similar wooden bins, each 9½ feet square by 24 feet deep, were used for comparing aerated and unaerated storage.

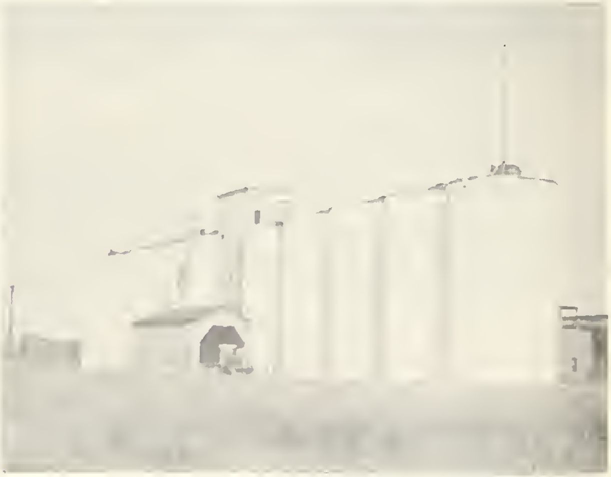

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Figure 4.--Upright storages, 32 feet in diameter and 60 feet high, in which aeration tests were made.

surface layers was determined from samples taken with experimental probes developed for the purpose. Standard instruments and gages were used to determine the airflow rates and the pressure required to force the air through the beans. Recording instruments provided continuous records of outdoor temperatures and relative humidity.

The results of the above tests are not discussed in detail but are used as examples to illustrate specific points in the planning, installation, and operation of systems for aerating stored pea beans.

PLANNING AERATION SYSTEMS FOR PEA BEAN STORAGES

Aeration of bulk-stored pea beans is a relatively new practice and many bean warehousemen have not fully understood the functions of the various parts of an aeration system. The system is composed of (a) ducts located in the beans, into which air moves from the surrounding bulk, (b) one or more fans to move the required amount of air through the stored beans, (c) supply pipes to connect the fans and the ducts, (d) a motor to operate each fan, and (e) controls to turn the fans on and off.

If an aeration system is to work effectively, all of the parts must be carefully selected in relation to the type of storage to be aerated. Types and capacities of storages vary widely, and there are many kinds and sizes of ducts, fans, motors, and other parts. Engineering services are essential, as engineering data on fans, ducts, movement of air through beans, and other requirements must be considered in the design of an aeration system.

Aeration involves the movement of natural air of selected temperature and humidity through bulk-stored pea beans, primarily to equalize the temperature of the beans in storage. This equalization occurs more quickly when high airflow rates are used, but equipment costs and power requirements rise rapidly as airflow rates increase and as the depth of the stored beans increases. Economy suggests the use of low airflow rates, but weather in the fall is often unsuitable for aerating the stored beans. To insure adequate aeration, therefore, certain requirements of airflow, duct size and arrangement, and fan operation must be met. The recommendations on planning, installing, and operating aeration systems for stored beans are based on research, observations, and industry experience from 1955 to 1959.

Airflow Requirements

The aeration studies in Michigan indicated that desirable airflow rates for pea beans are somewhat higher than for grain. Suitable weather for aerating pea beans is likely to be limited. Also, the air temperature range (45° to 32° F.) found to give the best results limits the hours of daily operation of the fan during the aerating period.

An airflow rate of 1/10 cfm per bushel proved to be satisfactory both in the aeration studies and in the experience of operators of bean receiving stations using aeration. Airflow rates as high as 1/5 cfm per bushel were used in the studies in flat storages. The added cost of supplying the higher airflow rate was not excessive and the rate of cooling was about twice as fast.

The resistance of pea beans to airflow is similar to that of shelled corn. Figure 5 shows the static pressure requirements for aerating pea beans at 1/20, 1/10, and 1/5 cfm per bushel when stored in bulk at depths ranging from 10 feet up to 120 feet. The static pressures were calculated from pressure data obtained during the aeration studies. [4]

Estimating Fan Horsepower and Static Pressure Requirements

Figure 5 also provides information for estimating the fan horsepower requirements for aerating pea beans. A static efficiency [5] of 47 percent was assumed in calculating the power requirements. Suppliers may furnish fans having a lower or a higher efficiency; then, the horsepower requirements given in figure 5 should be adjusted accordingly. Where the supplier specifies a fan efficiency other than 47 percent, the fan horsepower requirements can be recalculated as follows:

$$\frac{\text{HP per 1,000 bu. (fig. 5)} \times 0.47}{\text{Specified efficiency of fan}} = \text{HP required per 1,000 bu. for specified fan}$$

For example, assume a system requiring 0.2 HP per 1,000 bushels of beans when using a fan having a static efficiency of 47 percent. With a fan having a static efficiency of 35 percent, the system would require the following horsepower: $\frac{0.2 \times 0.47}{0.35} = 0.26$ HP per 1,000 bushels

To use the chart in figure 5 the following information is needed:

1. Total number of bushels of pea beans to be aerated.
2. Depth, in feet, of storage or maximum depth of beans.
3. Desired airflow rate in cfm per bushel.
4. Total volume (cfm) of air needed (bu. of beans x cfm per bu.).

An example of how to use the chart to determine fan and motor requirements. An aeration system to be designed for aerating pea beans at 1/10 cfm per bushel in a storage 60 feet deep and holding about 35,000 bushels:

1. Find 60 at bottom of chart (fig. 5).
2. Follow vertical line to 1/10 cfm curve.
3. Read static pressure on pressure lines on chart (broken line curving downward to right), in this case about 1.75 inches of water.

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[4] Static pressure, usually measured in inches of water, is a measure of the force or pressure that must be exerted on air to move it through grain and the aeration system. It is used in determining fan and horsepower requirements and in fan ratings furnished by fan manufacturers.

[5] Static efficiency of a fan is the ratio of the power output of the fan, based on capacity and fan total pressure, to the shaft power input.

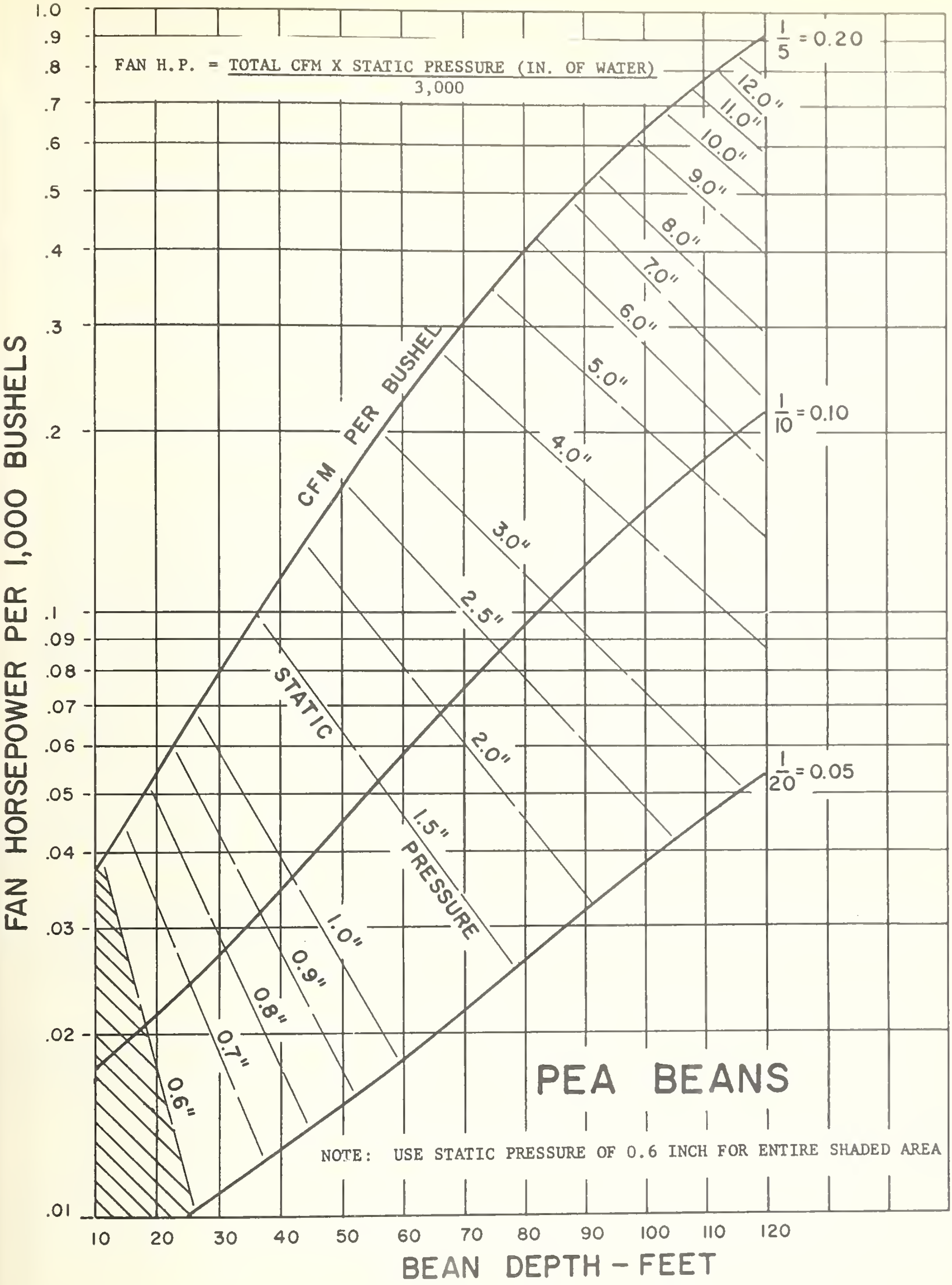

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Figure 5.--Fan horsepower required per 1,000 bushels to aerate pea beans stored 10 to 120 feet deep at specified static pressures and airflow rates.

4. Total air volume = 35,000 x 1/10 = 3,500 cfm.
5. Repeat Nos. 1 and 2 above, then follow horizontal line to left edge of chart. Read fan horsepower required per 1,000 bushels (on left hand ordinate of chart), in this case 0.06 horsepower.
6. Total power required = $\frac{35,000}{000}$ x 0.06 = 2.1 horsepower.

Therefore, in the above example the aeration system would require a fan that would deliver 3,500 cfm at 1.75 inches of water and a motor that would deliver at least 2 horsepower.

Types of Fans

The fan is an integral part of the aeration system and the system will not function efficiently unless an adequate fan is selected and properly connected to the system.

Both axial flow (propeller) and radial flow (centrifugal) fans can be used for aerating pea beans. Either type can be used where the total resistance of the beans and the system to airflow does not create a static pressure of more than 4 inches of water. Centrifugal fans are generally used for higher static pressures. Either type of fan is generally suitable for aerating pea beans at an airflow rate of 1/10 cfm per bushel if the height of the storage does not exceed 100 feet, or at 1/15 cfm per bushel if the height is not over 65 feet.

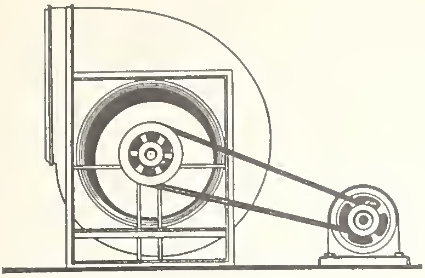
Three types of centrifugal fans are shown in figure 6. The "forward-curve" fan, (fig. 6-A) has a large number of blades and operates at a relatively slow speed. The major objection to this fan is that the motor may be overloaded if the static pressure is decreased so the fan delivers additional air.

A centrifugal fan with straight blades (fig. 6-C) is often referred to as a pressure fan or industrial exhauster. This type of fan is widely used in aerating grain in upright storages. It also overloads when the static pressure is reduced but not as much as a forward-curve fan.

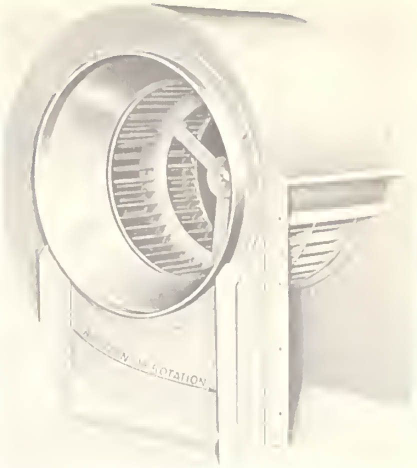
A "backward-curve" centrifugal fan, (fig. 6-B) has about 12 blades and is a high-speed fan. It is slightly more efficient, but more expensive, than a forward-curve or straight-blade fan. It has a self-limiting horsepower characteristic. If the motor size is adequate for fan operation near the point of greatest efficiency, there will be no danger of an overload.

Three types of axial flow fans are shown in figure 7. While essentially considered as low-pressure fans, certain designs are suitable for higher static pressures.

Fans should be selected on the basis of performance ratings supplied by the manufacturer and also with regard to the noise level, which may render certain fans undesirable for use in some urban locations. A performance rating specifies the volume of air delivered by the fan over a range of static pressure.

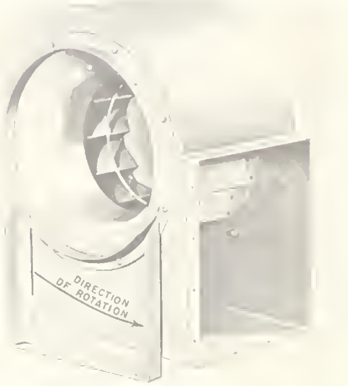


Centrifugal fan consisting of a fan rotor or wheel within a scroll type of housing. It is designed to move air over a wide range of volumes and pressures (up to 15 inches of water and above). The fan wheel may be equipped with radial tip blades or three other types.



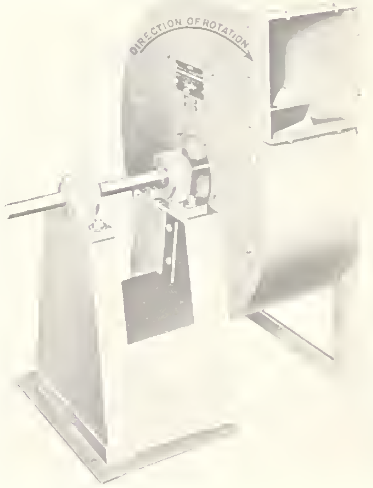
A

A. Fan wheel equipped with forward curve tip blade.



B

B. Fan wheel equipped with backward curve tip blade.



C

C. Fan wheel equipped with straight tip blade.

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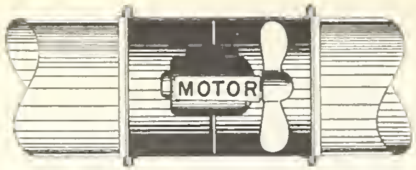
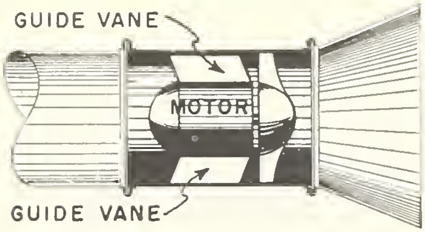
Figure 6.--Centrifugal fans.



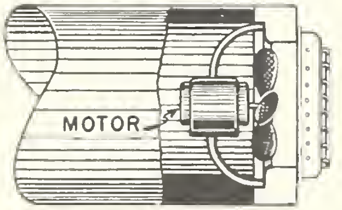
A. TUBEAXIAL FAN

A tubeaxial fan consists of an axial flow wheel within a cylinder. It is designed to move air through a wide range of volume at low to medium static pressures.



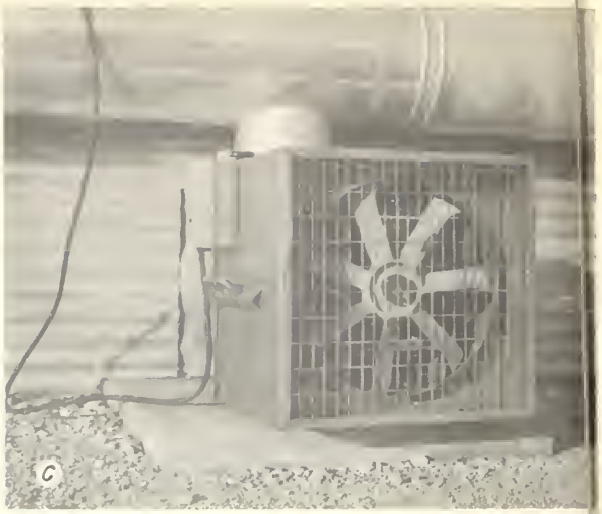
B. VANEAXIAL FAN

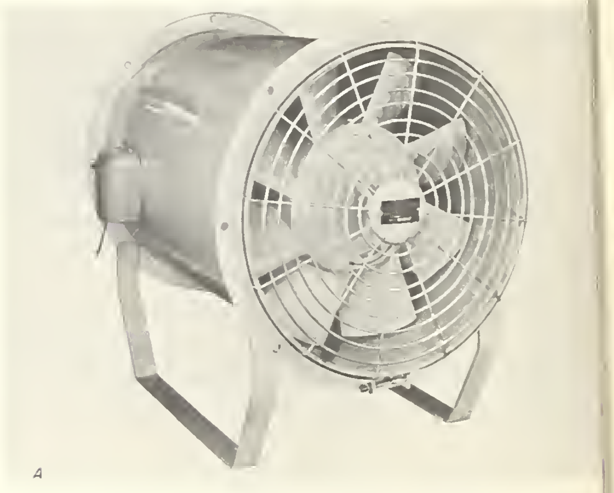
A vaneaxial fan consists of an axial flow wheel within a cylinder combined with a set of air guide vanes located either before or after the wheel. It is designed to move air over a wide range of volume and pressures.

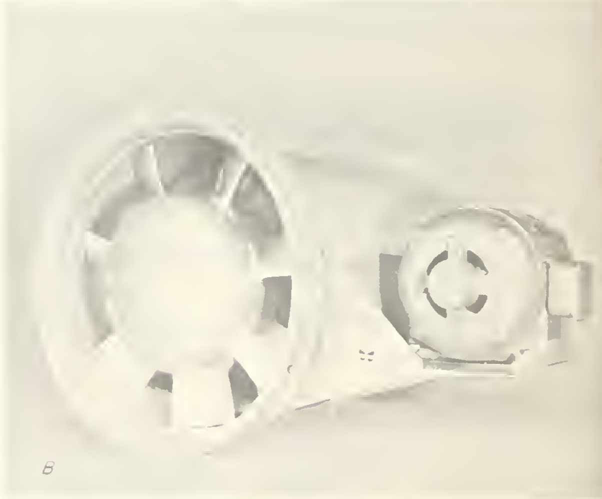


C. PROPELLER FAN

A propeller fan consists of an axial flow fan within a mounting ring or plate. It is designed to move air over a wide range of volume at low static pressures.







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NEG. BN-3883 AGRICULTURAL MARKETING SERVICE

Figure 7.--Axial flow fans.

Reliable performance ratings are assured if the fans selected are rated in accordance with the testing code of the Air Moving and Conditioning Association (formerly the National Association of Fan Manufacturers).

Fan Arrangements and Connections

An individual fan can be provided for each storage or for each duct in the storage. A large fan can be connected to several storages or to several ducts within a storage, or a single portable fan can be used to aerate several storages.

The individual fan arrangement is simple and versatile but generally more expensive than other arrangements. The multiple bin system with a supply pipe connecting one fixed fan to two or more bins or ducts generally costs less per storage and is convenient, as several storages or ducts can be served by actuating a single switch. Gate valves installed in the supply pipe permit aeration of selected storages; however, some air usually escapes around the valves and the pressure loss due to friction in the long supply pipe can be substantial unless the diameter of the pipe is great enough to minimize such losses.

The initial cost of equipment can be reduced by using a portable fan, but moving the fan frequently is inconvenient and there is a limit to the number of storages that can be aerated. There may be only a limited number of hours when weather is suitable for aerating pea beans in the fall after harvest and before extended periods of cold winter weather arrive. Therefore, it is advisable to limit the number of storages serviced by a portable fan to not more than three.

Regardless of fan arrangement, the system will not perform at its best unless the fan is properly connected. Air should enter the fan in as near a straight line as possible. Elbows such as those shown in figure 8-A restrict the airflow from the fan; an elbow with a larger throat (centerline) diameter will help to maintain the airflow (fig. 8-B).

Types of Ducts

Half-round or round metal ducts, corrugated or smooth, with perforations uniformly spaced over the duct surface are commonly used and generally are available commercially. The area of the perforations usually equals at least 10 percent of the total duct surface area. Perforations 3/32 inch in diameter or slots 5/64 inch wide will keep out normal-sized kernels of wheat as well as pea beans and other larger seeds.

Important dimensions of a duct system are: (1) The size--cross-sectional area--and the length, which influence the air velocity within the duct and the uniformity of airflow through the beans; (2) the surface area--circumference or perimeter--of the duct which affects the loss of static pressure in the beans or around the duct; and (3) the distance between the ducts--duct spacing--which influences the uniformity of airflow through the beans between the ducts.

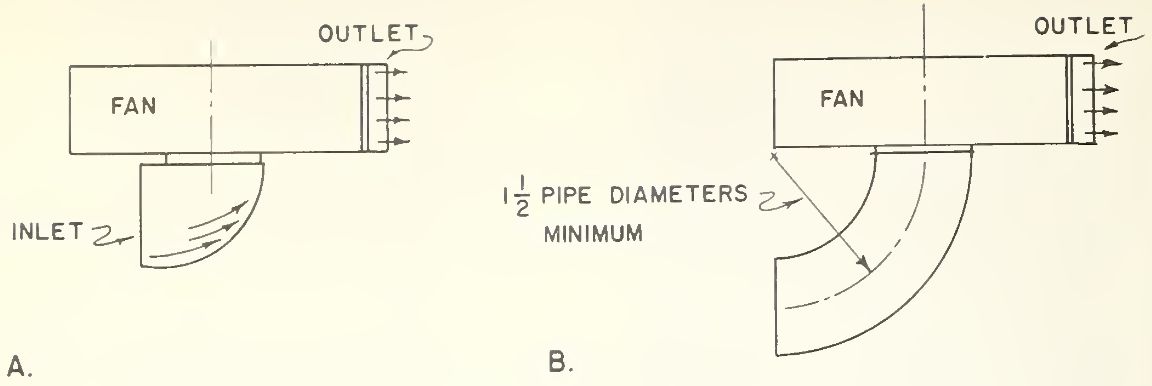


Figure 8.--Air should enter the fan in as near a straight line as possible.
A. Short inlet elbows restrict fan output.
B. Inlet elbows should have a centerline radius of not less than 1½ pipe diameters.

Duct Cross-Sectional Area and Length

The required cross-sectional area of a duct is governed by the amount of air the duct is to carry and by its length. Uneven airflow has been noted in flat storages where the maximum air velocity within the duct exceeded 1,500 feet per minute. The problem is more pronounced in long ducts and in ducts with rough or irregular surfaces.

Following is a list of recommended maximum air velocities within ducts of varying lengths, including those with interior supports or framing and wire and mesh covering:

Duct Length	Air velocity within duct f.p.m.
5 to 25 feet	2,000 to 1,500
25 to 60 feet	1,500 to 1,000
60 to 100 feet	Less than 1,000

The required cross-sectional area of ducts can be determined from the above data if the total air volume and duct length are known. The total air volume divided by the maximum air velocity equals the minimum cross-sectional area.

$$\frac{\text{Total air volume (cfm)}}{\text{Air velocity (fpm)}} = \text{cross-sectional area (sq. ft.)}$$

Surface Area

Limiting the velocity of the air moving through the beans surrounding the duct prevents excessive pressure losses in this area. This velocity is influenced by the amount of surface area of the duct and the airflow rate used.

For upright storages it is desirable to have sufficient surface area so that the velocity of the air moving through the beans around the duct will be around 30 feet per minute (fpm) and never over 50 fpm.

The surface area may not be the controlling factor in designing ducts for flat storages, as the quantity of beans served per square foot of surface area usually is smaller than in other types of storage. However, both the surface and cross-sectional areas must be checked against the minimum requirements.

For common airflow rates, the total static pressure in flat storages is less than in upright storages. Therefore, a relatively high static pressure in the beans near the duct represents a higher percentage of the total static pressure. Consequently, ducts in level-loaded flat storages should have sufficient surface area to limit the air velocity in the beans near the ducts to 20 fpm or less.

The total square feet of duct surface area required can be determined by dividing the total volume of air handled by each duct by the selected air velocity in the beans near the duct. For example, if a duct is to handle 965 cfm and the selected air velocity is 30 fpm, the total surface area required is $\frac{965\ \text{cfm}}{30\ \text{fpm}} = 32.2$ sq. ft. Thus, a duct 8 feet long would require 4 square feet of surface area per foot of duct length. $\frac{32.2\ \text{sq. ft.}}{8\ \text{ft.}}$ x 1 ft. length = 4 sq. ft. per lineal foot. A standard 36-inch diameter, half-round, corrugated and perforated duct with 4.72 square feet of surface area per foot of length would be suitable. Or other types of ducts having similar cross-sectional and surface areas could meet these requirements.

Figure 9 shows the static pressures observed during tests in a flat storage where the maximum air velocity within the duct was calculated to be about 2,100 fpm. The higher pressures near the fan end of the duct indicate that the airflow through the beans was considerably higher than at the far end of the duct. (See figure 18, page 31, for cooling pattern). The pressure readings, and the spacing of the pressure lines, should be fairly uniform throughout the length of the duct for uniform airflow and uniform cooling. Ideally each line should be about parallel to the duct.

Spacing

A single duct of the type shown in figure 10 frequently is used in upright storages up to 30 feet in diameter.

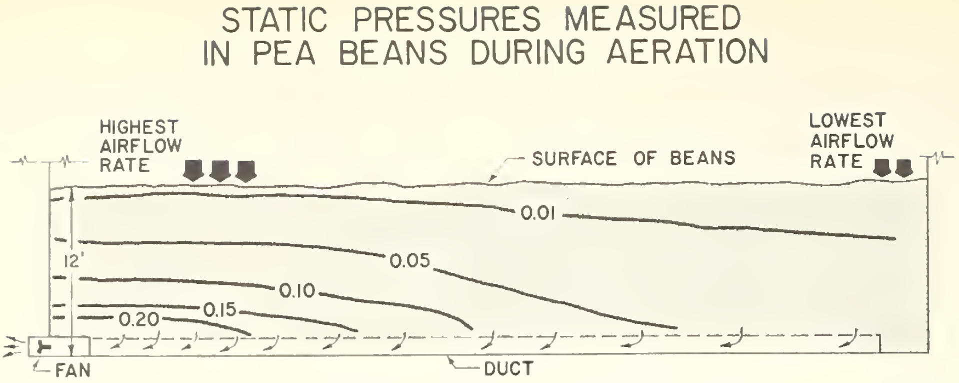


Figure 9.--Static pressures (in inches of water) measured in pea beans stored in a flat storage 60 feet long and aerated at 1/5 cfm per bushel.

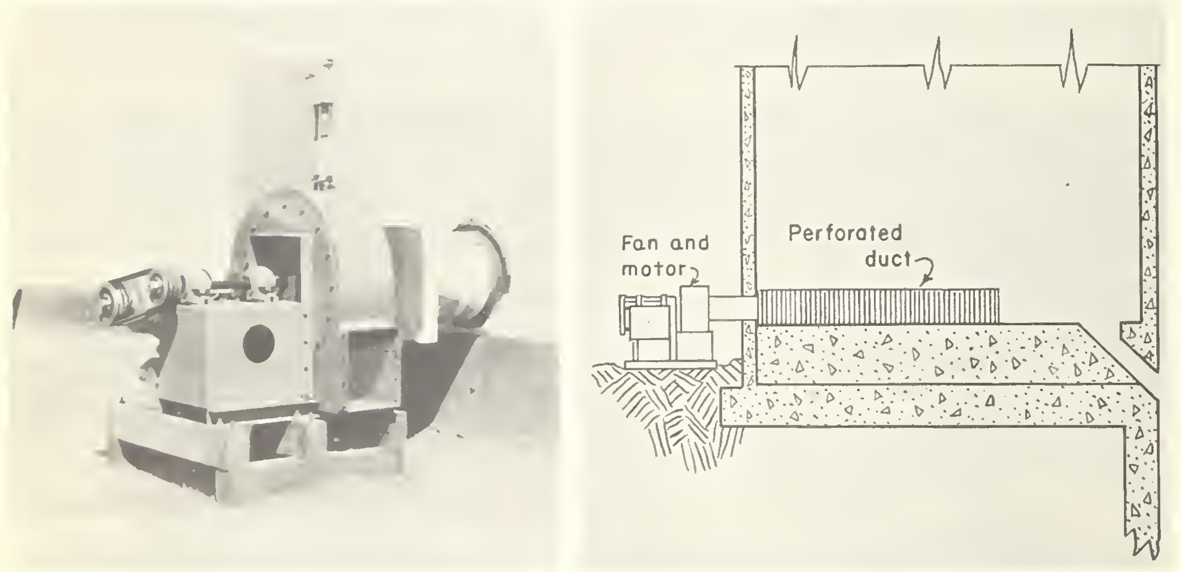
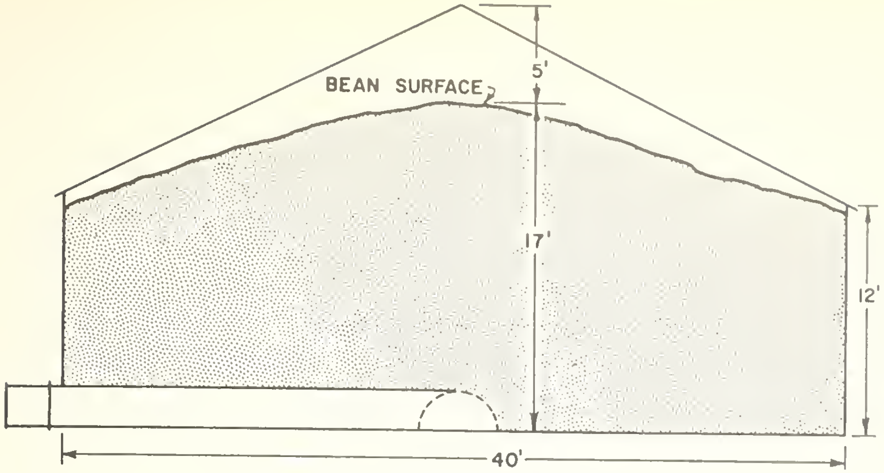
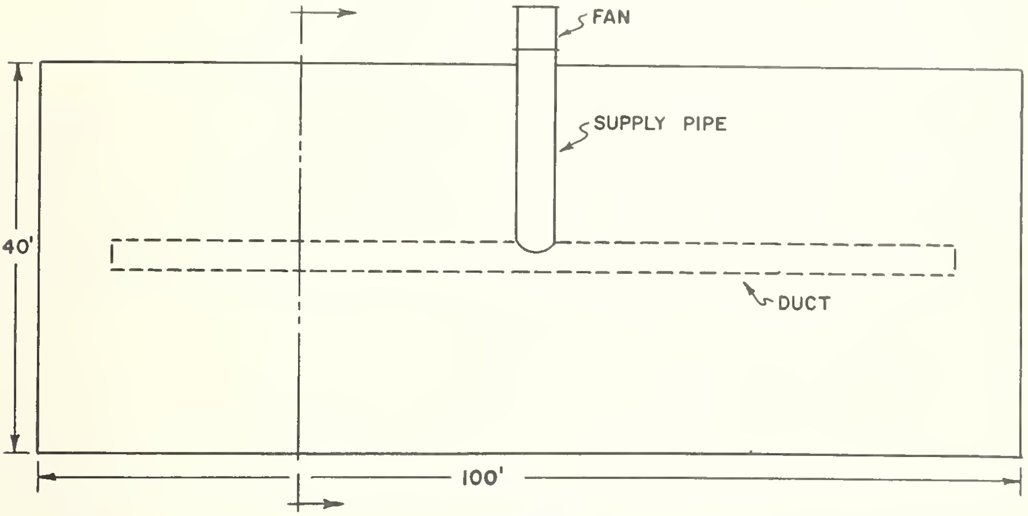


Figure 10.--Aeration system with a single duct for upright storage with flat bottom.

In flat storages the duct spacing is related to the building dimensions as well as to the depth and shape of the mass of stored beans. Prefabricated flat storages are available in standard widths ranging from 40 to 150 feet; lengths can be increased by adding additional sections or units. Also, these storages are commonly available with 1/6 to 1/3 roof pitches. Generally, in storages 40 feet in width, one duct is placed lengthwise down the center of the building (fig. 11). However, where the depth of beans is considerably less than 20 feet, two ducts are suggested.



A. SECTION



B. PLAN

Figure 11.--Single lengthwise duct in a flat storage with supply pipe connected at middle of duct. (A) Cross-section through storage. (B) Floor plan.

In flat storages over 40 feet wide, 2 or more ducts are used when the ducts are placed lengthwise of the building. With level loading, the spacing between the ducts should be no more than the depth of the beans.

The farther apart the ducts, the less uniform the airflow is likely to be. This is illustrated in figure 12 where the duct spacing is greater than the bean depth. The static pressures listed were observed during the aeration studies. The shape of the static pressure curves shows that the airflow near the floor between the ducts is much lower than the airflow around and above the two ducts.

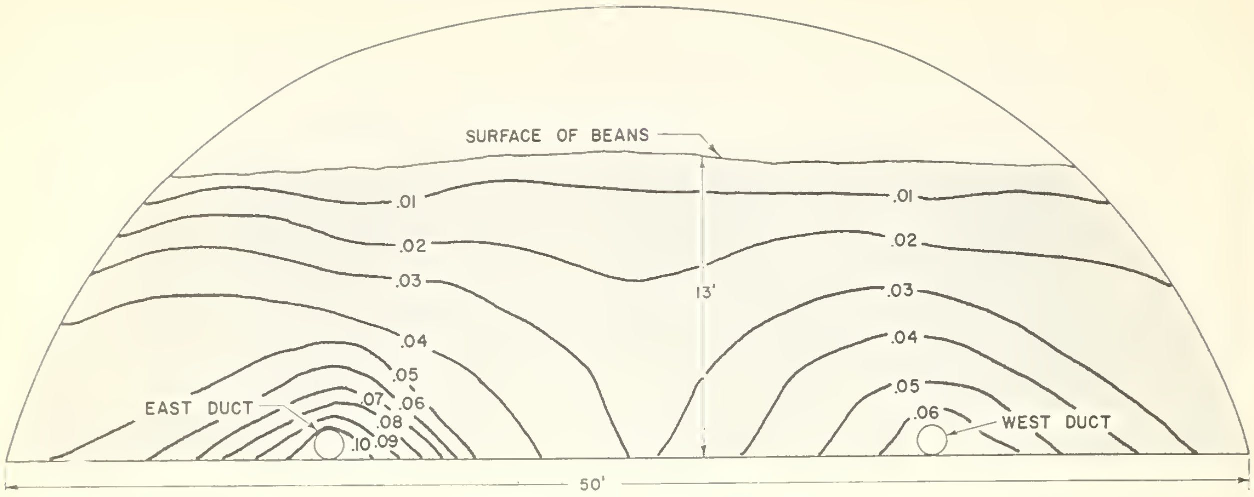


Figure 12.--Static pressures (in inches of water) observed in aerated flat storage where the space between the ducts is greater than the depth of the beans.

Ducts also can be placed crosswise of the storage to make it easier to unload the storage. In long buildings this arrangement helps to shorten the length of the ducts. Fans are placed at the end of the ducts on the sides of the storage. With peaked loading, special arrangements must be made to provide adequate airflow through the greater depths of beans with ducts installed crosswise. Commercial aeration systems are available for peak-loaded flat storages.

Supply Pipes

Supply pipes provide for passage of air between the duct and the fan. They usually are round and made of smooth sheet metal. They should be well supported and anchored. A maximum air velocity of 2,500 fpm is permissible within supply pipes, but 1,500 to 2,000 fpm is preferred.

It often is necessary to use elbows to make turns in supply pipes. Elbows range in shape from the simple square (miter) elbow to the multiple-piece elbow (fig. 13). The square elbow should be avoided because of the relatively high losses in pressure due to friction in such an elbow. On the other hand, there is little gain in using elbows with more than five pieces for small pipes or more than seven for large pipes. Elbows with a centerline radius equal to at least 1.5 pipe diameters (fig. 13) are considered acceptable and desirable with respect to both installation and operation.

The loss of air pressure in an elbow is often expressed as the length of straight pipe (of the same shape and diameter) which would give an equivalent loss of pressure. To illustrate the comparative pressure losses in the square elbow and the 3-piece elbow shown in figure 13, assume that the diameter of the two elbows is the same and each elbow carries an equal volume of air. Under these conditions the losses in the square elbow would be about four times greater than in the 3-piece elbow.

Abrupt changes in pipe sizes also cause losses in air delivery. Figure 14-A shows a fan connection with an abrupt expansion resulting in air turbulence and a reduction in airflow. Increasing the length of the connections as shown in figure 14-B reduces the loss of air delivery.

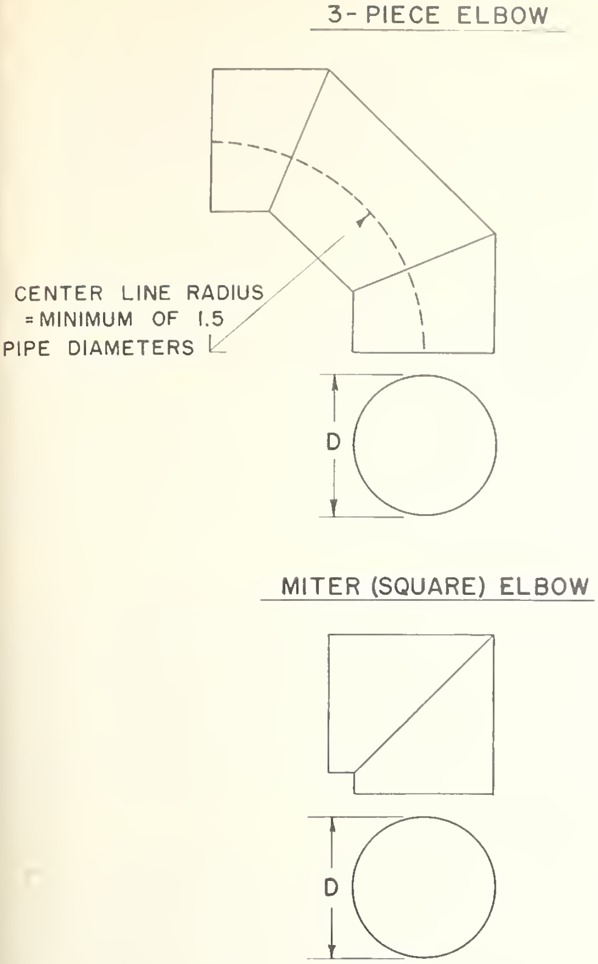


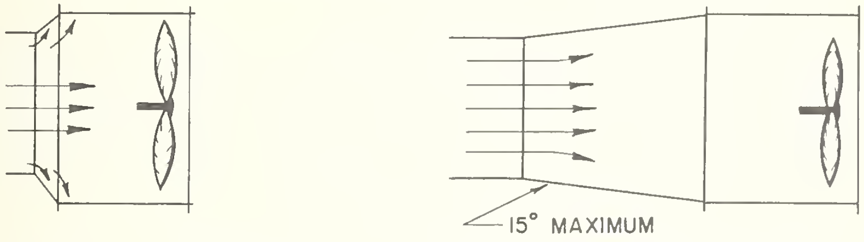
Figure 13.--Two types of elbows for making turns in supply pipes.

Electric Motors

Electric motors are generally used to drive aeration fans. Most fans require only low to medium starting torque, and aeration installations usually are designed for operation at constant speed. Thus, the more simple motors are suitable for driving fans.

The type of motor selected will depend on the electric service available and the power supplier's regulations. Three-phase motors come in standard sizes from 1.8 horsepower upward and are generally used wherever 3-phase power is available.

Single-phase motors are suitable for fan operation, but are more expensive than 3-phase motors. Many power companies object to the use of single-phase motors over 7½ horsepower. A totally enclosed, fan-cooled motor



A. ABRUPT EXPANSION CAUSES AIR TURBULENCE.

B. INCREASING LENGTH OF PIPE CONNECTIONS IMPROVES AIR DELIVERY.

Figure 14.--(A) Good and (B) bad duct-fan connections.

of either type is usually required for aeration duty where grain dust is present or weather protection is needed.

A motor and fan unit is often purchased. The fan manufacturer will provide a motor with adequate power to deliver the quantity of air against the static pressure specified by the customer. The customer must also specify a 3-phase or single-phase motor and the voltage for the motor.

If a motor is purchased separately, the horsepower required for the operating conditions of a particular fan can be found in the fan manufacturer's catalog. In selecting the size of motor for operating a fan, it is advisable to select the next standard size larger than the minimum horsepower requirements given in the fan catalog.

Controlling the Aeration System

Air Temperature and Fan Operation

The operation of aeration fans must be controlled if beans in bulk storage are to be properly aerated, as the beans will approach the temperature of the air drawn through the beans. Thus, the bean temperature can be regulated by operating fans when the air temperature is right. Bean temperatures should be established that are low enough to prevent convection currents from developing in the stored beans during cold weather but not so low that excessive physical damage will occur when beans are removed from storage.

Bean temperatures of 45° F. and below will prevent harmful convection currents from becoming established in bulk stored pea beans during the normal storage period. A low temperature limit of 32° F. has been satisfactory in preventing the beans from becoming excessively cold. The temperature range between 45° and 32° F. allows adequate fan operation for proper aeration in most weather.

Moisture may condense on cold beans when they are removed from storage if outside air temperature and relative humidity are high. During the 4 years of study, however, no condensation was observed on pea beans cooled to a temperature range of 30° to 45° F.

Air Humidity and Fan Operation

Pea beans will absorb moisture from damp air. Dexter and others [6] have shown that pea beans will assume a moisture content of 18 percent when exposed to air at 80 percent relative humidity and between 40° and 70° F. In some tests the bulk-stored beans absorbed moisture during aeration with air of high humidity. It is recommended, therefore, that beans not be aerated when the relative humidity of the air is above 80 percent.

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[6] Dexter, S. T., Anderson, A. L., Pfahler, P. L., and Benne, E. J., Responses of White Pea Beans to Various Humidities and Temperatures of Storage. Agron. Jour., Vol. 47, No. 6. June 1955.

Some drying usually occurs during aeration, as the cooling air moving through the warmer beans is warmed and is then able to hold more moisture. This drying is not great, however, as an appreciable amount of moisture cannot be absorbed by air at the temperatures normally encountered in stored beans. A shrinkage of less than 0.4 percent was observed in one aerated bulk storage from November to June. Maximum weight losses in wheat and corn are 1 to 1.5 percent, and there is little reason to expect that losses for pea beans will exceed this amount.

Methods of Controlling Fan Operation

Manual.--Aeration fans can be controlled by manually switching them "on" and "off." However, it is necessary to determine periodically the temperature and humidity of the air during fan operation to be certain that proper air conditions prevail. This can be done by using a psychrometer in accordance with the recommendations of the manufacturer or of the Weather Bureau. [7] The frequency of these checks will depend on how rapidly the weather changes.

Automatic.--Aeration fans can be controlled automatically by temperature-sensitive switches (thermostats) and humidity-sensitive switches (humidistats). Two thermostats should be used and connected in series. One should be set to open near the upper temperature limit (45° F.), and the other to open near the lower temperature limit (32° F.) so that the fan will operate only when air temperatures are between the two limits. The humidistat should also be placed in series with the thermostats and adjusted so that the fan will not operate when the relative humidity of the air is above 80 percent.

The automatic controls should be carefully adjusted and the manufacturer's recommendations for maintenance and adjustment followed closely. The adjustment of humidistats with hair elements should be checked every week or 10 days, preferably at the 32° to 45° F. temperature range and at relative humidities of 80 percent or higher.

It is important that the automatic controls be located so that they truly reflect the temperature and humidity of the air that is to be drawn through the beans. They should be located in the shade where natural outside air will circulate freely around them. Dirt and dust should be avoided as much as possible as these may affect the accuracy of the humidistat. A well-ventilated box that will not absorb appreciable heat from the sun is advisable. Instrument shelters used by the U. S. Weather Bureau are good examples of suitable boxes for aeration controls.

Automatic controls insure maximum hours of fan operation when the weather is suitable, and the fan requires less attention during the aeration periods.

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[7] Marvin, C. F. Psychrometric Tables for Obtaining the Vapor Pressure, Relative Humidity, and Temperature of the Dewpoint. U. S. Weather Bureau, Weather Bul. No. 235, 88 pp. (illus.), 1941. (Available for 30 cents from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.)

General Considerations

The aeration system should be designed with consideration being given not only to the type of storage, but to the method of loading and unloading the storage, the location of the temperature-indicating equipment, and whether or not the beans will be leveled.

The last place to cool in a bulk storage usually is near the floor and between the ducts when more than one duct is used. It is advisable to locate temperature-indicating equipment in these areas so that it will be possible to determine when aeration is complete. This is particularly important in flat storages.

The method of loading and unloading a flat storage should be considered in placing the ducts and temperature-indicating equipment. Filling a flat storage from relatively few locations may cause piling and considerable surface unevenness (fig. 15). If the beans are not leveled it is desirable to have temperature-indicating equipment in the center of the piles. Air will move more slowly through these piles because of increased resistance to airflow and accumulation of foreign material. The ducts should extend through the piles to provide satisfactory air movement. If unsatisfactory storage conditions result despite these precautions, it may be necessary to level the beans.

Consideration should be given to the method of unloading when locating and arranging ducts in flat storages. As unloading progresses, it usually is easier to remove the ducts when they are parallel to rather than at a right angle to the direction of unloading.

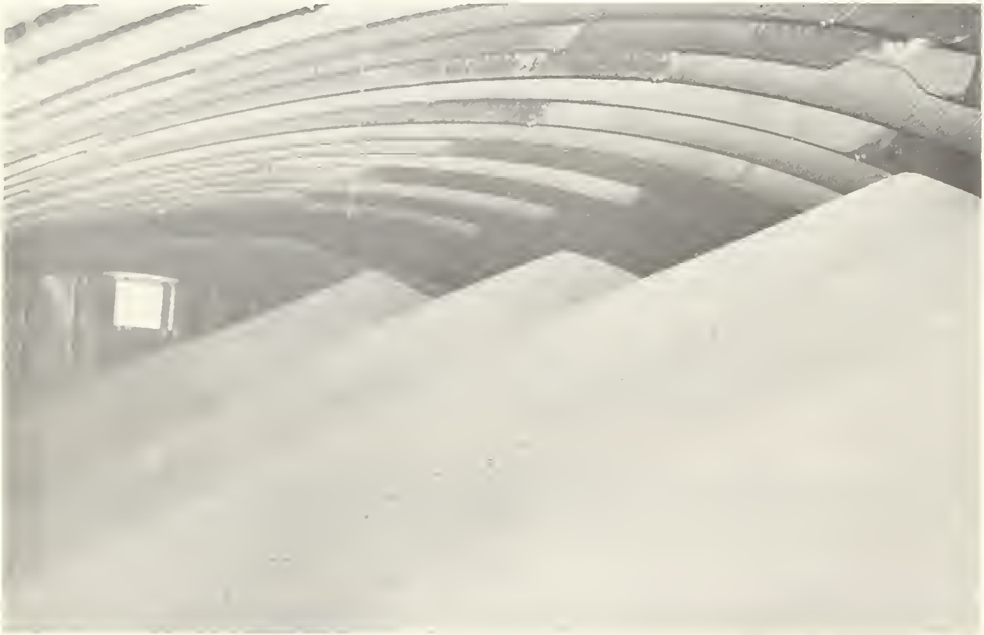

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Figure 15.--Conical piles of beans resulting from the uneven filling of a flat storage. Nonuniform airflow and delayed cooling can occur in such piles.

Flat storages are often used during the spring and summer for the storage of bagged beans or other commodities. Thus, in selecting ducts, it is wise to consider if they will be removed and handled frequently. Some types of ducts can be removed and stacked easily while others must be handled carefully if they are not to be damaged.

It is sometimes desirable to aerate beans before the storage is completely filled. In upright storages the airflow usually will be uniform and aeration will be satisfactory. In flat storages, however, airflow will not be uniform unless the ducts are covered with an equal depth of beans. If a duct is not covered with beans, it should be closed off so that the air does not "short circuit" or bypass the beans covering other ducts. The exposed duct surface can be covered with canvas or other air resistant material. This covering should extend well up onto the bean pile so that the air path through the beans to the duct is reasonably uniform. In level but shallow filling there may be inadequate airflow through the beans between the ducts. More uniform airflow can be secured by placing strips of air-resistant material on top of the beans above the ducts to force air through the beans between the ducts.

OPERATION OF THE AERATION SYSTEM

How Beans Cool

Aeration systems generally are designed to draw air down through the stored beans and exhaust it through the fan. An alternative method is to force the air up through the beans, exhausting it through the beans at the surface. However, these surface beans may be cooled during cold weather when the fan is not in operation. During subsequent operation the warm, moist air coming up from the warmer beans will be cooled as it hits these cold beans. As the cooled air cannot hold as much water, some moisture may condense on the beans. Excessive moisture may cause the beans to spoil.

Cool air drawn down through bulk-stored beans absorbs heat quickly so that it moves only a few feet before it approaches the temperature of the uncooled beans. Thus, as the beans are aerated, cooling layers or zones move down through the beans. The beans below the front of the cooling zone remain uncooled, while those above the zone are cooled to near the temperature of the incoming air. Cooling zones, represented by closely spaced temperature lines, are illustrated in figure 16.

Warm areas, or "hot spots," occasionally develop in beans not in proper condition for storage. These areas develop because of mold and insect activity and can cause extensive deterioration of beans. Fortunately, these hot spots generally can be removed from stored beans by aeration. A hot spot cannot be effectively dissipated in the bean mass. Rather, the cool air being drawn through the beans gradually moves the hot spot through and out of the beans.

Cooling zones should be moved completely through the beans before aeration is stopped. Otherwise, cool and warm beans are adjacent in the storage; if moisture migrates from the warm to the cool beans, unsafe storage conditions may result. This transfer of moisture usually is slow, however, and if aeration

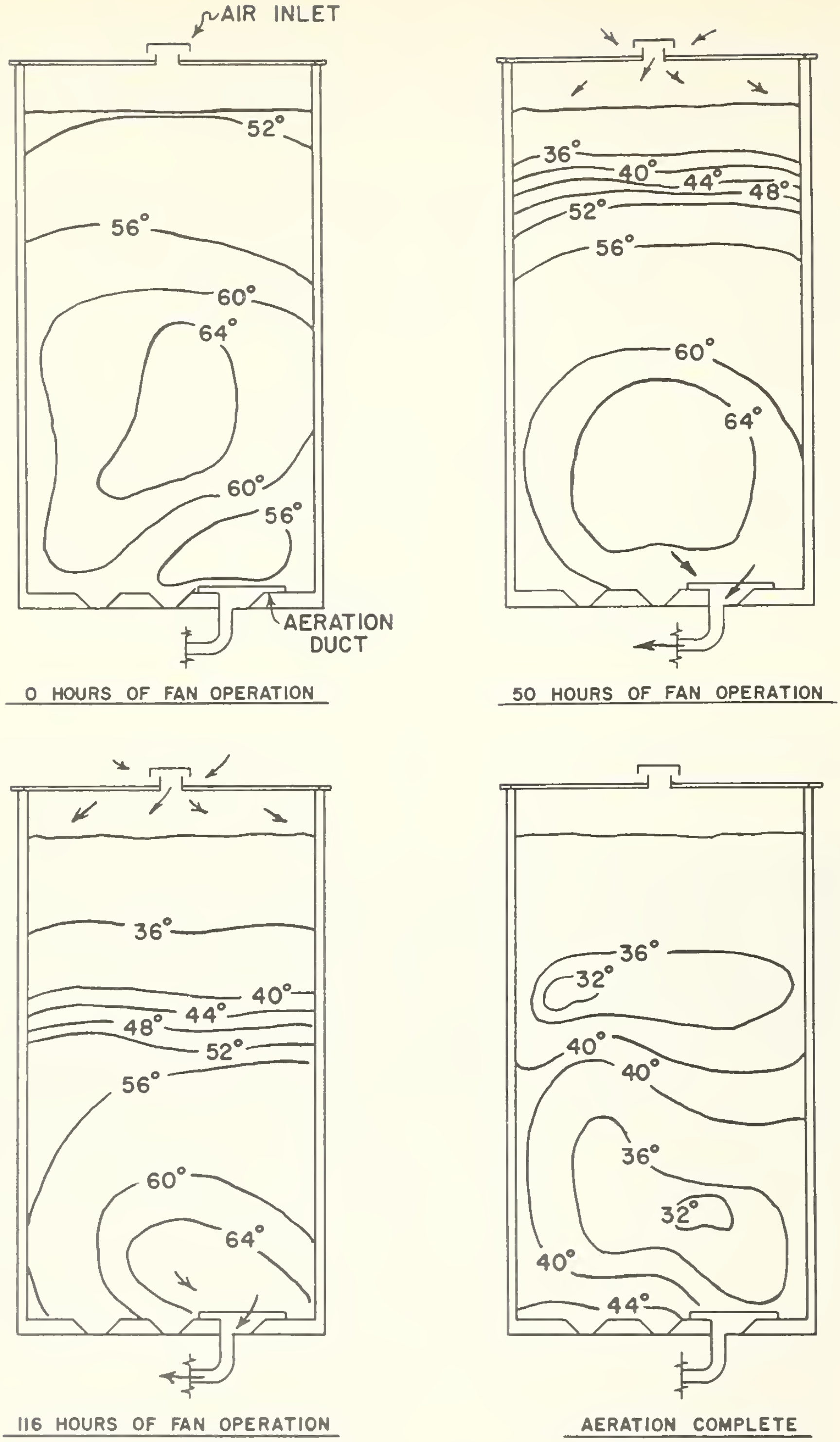

Figure 16.--Temperature changes in aerated pea beans stored in a vertical (silo) storage.

is completed within 30 to 60 days, appreciable migration and accumulation of moisture are not likely.

In upright storages, around 150 hours of aeration at 1/10 cfm per bushel will be required to cool beans to near the outside temperature. At 1/5 cfm per bushel, about half this time will be required. At a specified airflow rate the hours of fan operation required for cooling are substantially the same regardless of the initial temperature of the beans. Airflow usually is not as uniform in flat storages as in upright storages. For example, at 1/10 cfm per bushel, more than 150 hours of fan operation may be required to complete the cooling of the beans near the floor between the ducts.

Bean Temperatures

Measuring the temperature of stored beans is important because it can indicate: (1) The condition of the beans, and (2) the progress of aeration by the amount of cooling and equalizing of temperatures accomplished. Temperatures can be measured with thermocouple cables inserted into the beans. Thermocouple junctions usually are placed 3 to 6 feet apart on the cables. For upright storages up to 20 feet in diameter, a single cable generally is used; additional cables are added for larger storages. In flat storages, cables are spaced no more than 20 feet apart and preferably closer.

Temperature of the beans should be observed periodically throughout the storage period so that any changes can be readily noted. It is advisable to record temperatures once or twice a week for the first few weeks of storage. Following this, reading temperatures every week or two is usually sufficient. While the fans are in operation, however, daily temperature readings are advisable so that the movement of the cooling zones can be accurately established.

The temperature of pea beans when placed in storage in Michigan is often around 60° to 70° F. Aeration should be started soon after storage, particularly if bean temperatures are initially above this usual range or if they increase, or if appreciable field damage is present and the moisture content is near the upper limit of 18 percent. Temperature increases usually indicate mold and bacterial action, which can become increasingly severe and cause the beans to spoil.

Temperatures of beans aerated at 1/10 cfm per bushel in a storage (silo) 32 feet in diameter and 60 feet high are illustrated in figure 16. Changes in the position of the cooling zone, evident by the closely spaced temperature lines, are shown in figure 16. Beans at temperatures of 52° to 64° F. were cooled to 32° to 40° F., well within the 32° to 45° F. fan-control settings.

Bean temperatures in an unaerated silo similar to the aerated one are presented in figure 17. The original temperatures ranged from 56° to 64° F. on November 3. On December 31 the range was from 44° to 72° F. and on February 15 from 32° to 76° F. Temperatures of the beans increased in this storage, particularly toward the upper surface. By the end of January the moisture content of the beans in the surface layers had increased from about 17 percent

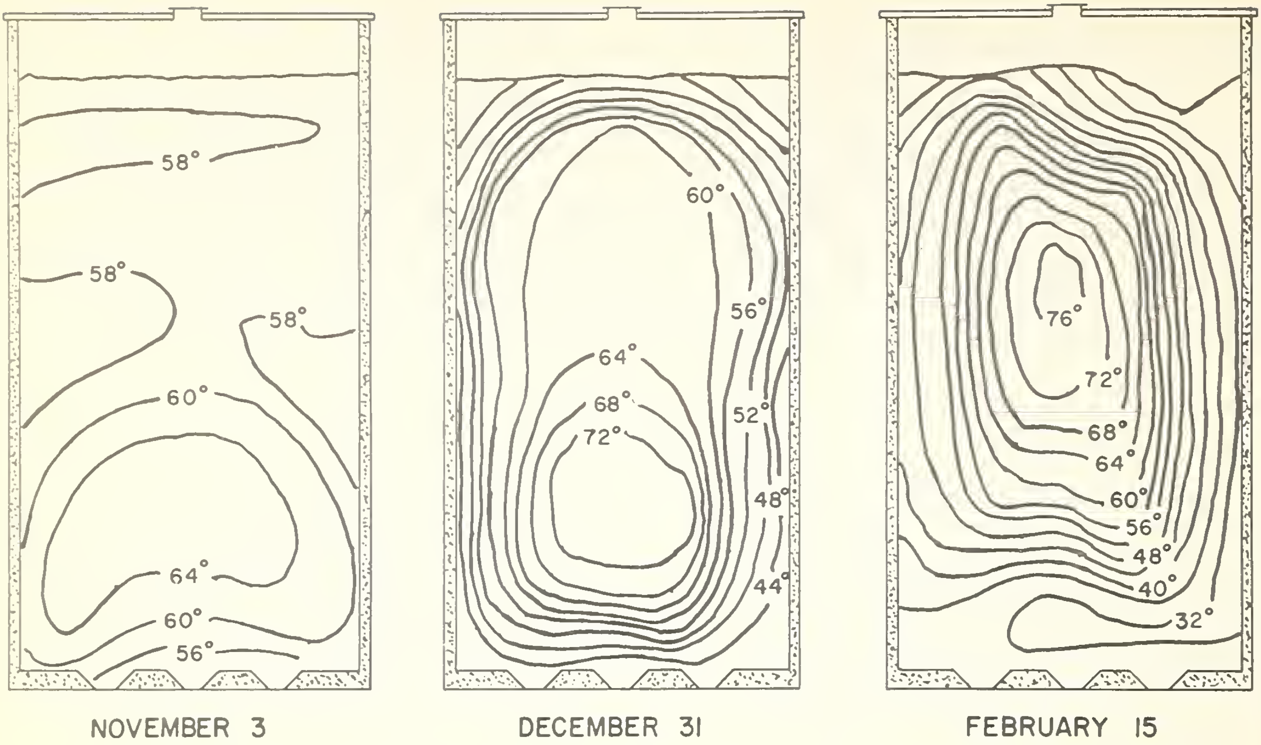

Figure 17.--Temperature changes in unaerated pea beans stored in a vertical (silo) storage.

to well above 18 percent, and the beans were not in a suitable condition for storage. The movement of the warm air toward the surface was evidence of convection currents present in the stored beans.

Temperatures of pea beans in aerated flat storages are illustrated in figure 18. Initial temperatures ranged from 36° to 56° F. throughout the storage. Temperature patterns after 62 hours and 135 hours of fan operation at about 1/5 cfm per bushel are shown. The cooling zone is evident by the closely spaced temperature lines. Figure 18 clearly illustrates that the last area to be cooled was between the ducts along the floor.

The bean temperatures in figure 19 were observed in a flat storage with relatively long ducts where the maximum air velocity within the duct was calculated to be about 2,100 fpm. The temperature lines show that the cooling was faster near the fan end where the airflow and the static pressure were highest.

Fan Operating Procedure

Aeration should start as soon as possible after the beans are placed in storage, especially if the beans have field damage and are near the upper moisture limit for safe storage. As with other perishable products, deterioration of pea beans is progressive. Any measures that can be taken to stop or retard this, such as prompt cooling by aeration, are advantageous.

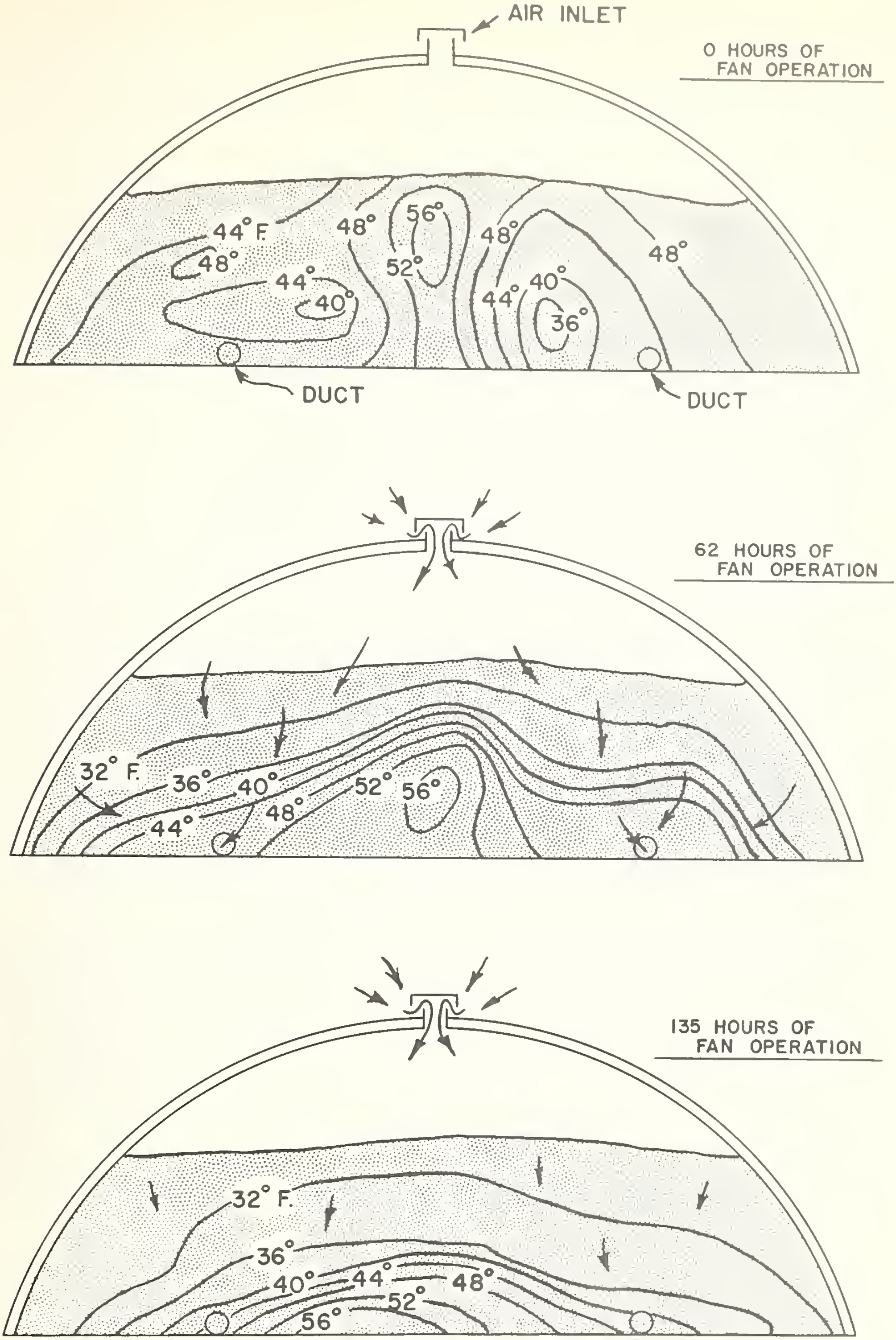

Figure 18.--Temperature patterns in aerated pea beans in a flat storage show that the last area to be cooled is near the floor between the ducts.

BEAN TEMPERATURE PATTERNS DURING AERATION

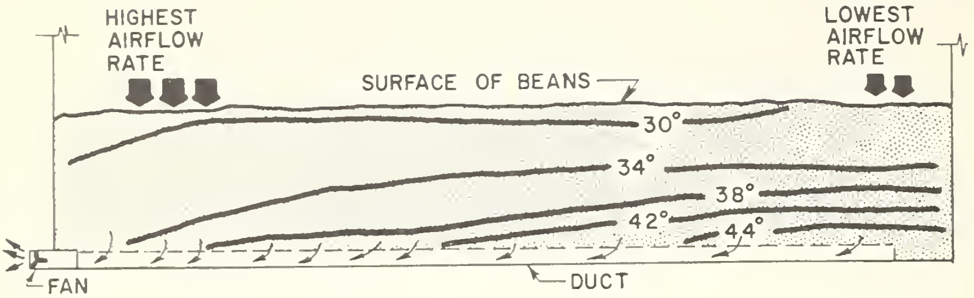

Figure 19.--Bean temperature (° F.) in an aerated flat storage (downward airflow). Beans cool fastest at fan end, where airflow is highest.

Occasionally the weather may be warm during the first part of the fall storage period, and it may be desirable to reset the controls above the recommended setting so that the fan will operate at a higher temperature range. In such instances, control settings between 45° and 60° F. are suggested, with no operation when the relative humidity of the outside air is above 80 percent. Some 150 to 200 hours of fan operation will be required to move the cooling zone completely through the beans. Control settings should then be returned to normal (32° to 45° F.) and a second cooling zone moved through the beans to further reduce their temperature. Moving more than one cooling zone through the beans is known as "stage" cooling. When the temperature of the beans has been reduced and equalized, there is no advantage to continued extensive operation of the fan.

Pea beans are living organisms that respire as do other living seeds and grains. They absorb oxygen and give off carbon dioxide and other volatile materials, some of which are thought to be responsible for the "beany" or "storage" odors characteristic of stored beans. Warehousemen generally consider it desirable to remove these odors, although information is lacking as to whether or not they are detrimental. There is some evidence that these odors can be dissipated by operating the fan for several hours every 2 to 4 weeks under temperature and humidity conditions normally recommended for aeration. Checking the exhaust air from the fan periodically is helpful in telling when storage odors have been removed.

Pea beans usually are removed from storage in the spring while the weather is still cold, but occasionally it is desirable to hold them after warm weather has arrived. However, the beans near the upper surface and those near the walls may warm up because of the warm weather. Then it is advisable to aerate at night when the air is cool if any appreciable unevenness in bean temperature is observed. Only limited experience has been reported with "spring season" aeration. Its principal purpose is to equalize the temperature of the beans. It also prevents rapid rises in the beans near the surface and exposed wall areas, brought on by the warm daytime air temperatures, and tends to reduce spoilage in these areas.

Test Sampling of Beans

It is advisable to sample the surface layers of stored pea beans periodically to determine whether or not moisture is accumulating. Samples should be taken at the start of the storage period and every 2 to 4 weeks thereafter. The sampling areas should be located throughout the storage and marked so that samples can be taken later from these same areas for comparison (fig. 20). Sampling in each area at depths of 6 inches and 12 to 18 inches is recommended. Samples should be taken near, but not at, the exact location of previous samples. Moisture analyses should be made of the samples and the results recorded so that changes in moisture during the storage period can be observed.

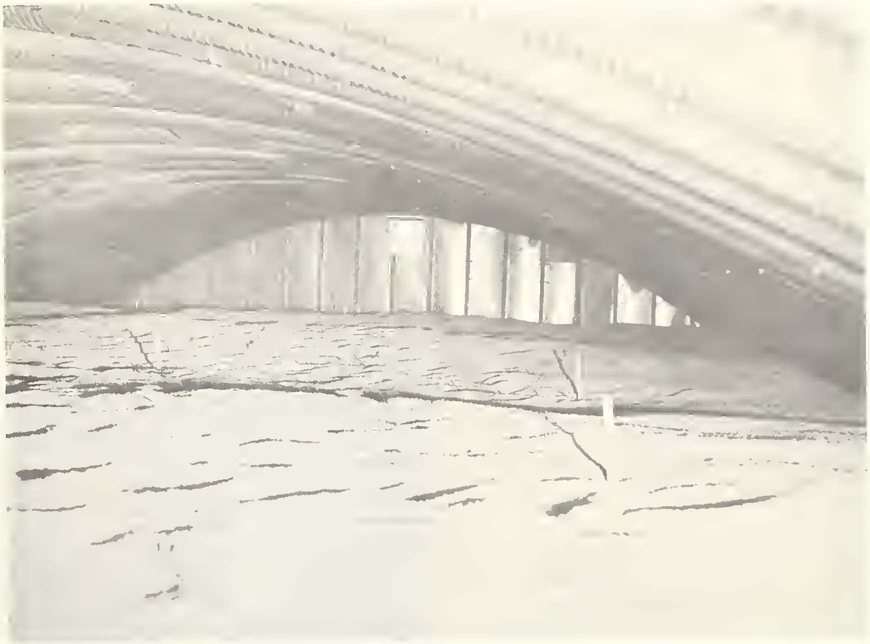

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Figure 20.--The surface of a flat storage, leveled after filling to insure uniform airflow. Small stakes in the beans indicate the location of test sampling areas.

In flat storages where beans are left in piles (fig. 15) it is important to inspect the peaks of the piles, as moisture usually accumulates there first. If moisture has increased, the peaks should be leveled. If the moisture accumulation is excessive and mold has developed, it may be necessary to "scalp" or remove the moldy and moist beans to prevent additional damage. Moisture increases and molding usually are confined to surface layers. When the beans are cold or weather is not suitable for aeration, additional aeration cannot be used to advantage to prevent moisture accumulation and molding. Aeration does not insure that beans in poor storage condition will keep satisfactorily.

The moisture content of pea beans in the upper 24 inches of an aerated and unaerated bin, during a typical storage season, is given in tables 1 and 2. These beans were stored in two similar wooden bins, each 9½ feet square and 24 feet deep. One bin was aerated at 1/10 cfm per bushel and the other bin was not aerated. Samples were taken at depths of less than 6 inches, 6 to 12 inches, and 18 to 24 inches at locations shown in figure 21.

Average moisture of the beans in the samples taken on October 3 (when the unaerated bin had just been filled) and on December 12 is shown in the following tabulation:

Depth below surface	October 3		December 12	
	Aerated bin	Unaerated bin	Aerated bin	Unaerated bin
	Percent	Percent	Percent	Percent
Less than 6 inches.	17.9	17.7	16.6	24.6
6 to 12 inches.	18.1	17.7	16.1	20.4
18 to 24 inches	18.2	17.7	16.8	18.4

Moisture continued to accumulate in the surface layers of the unaerated bin and the beans were removed from storage on January 6 (fig. 22). Meanwhile, the beans in the aerated bin remained in good storage condition.

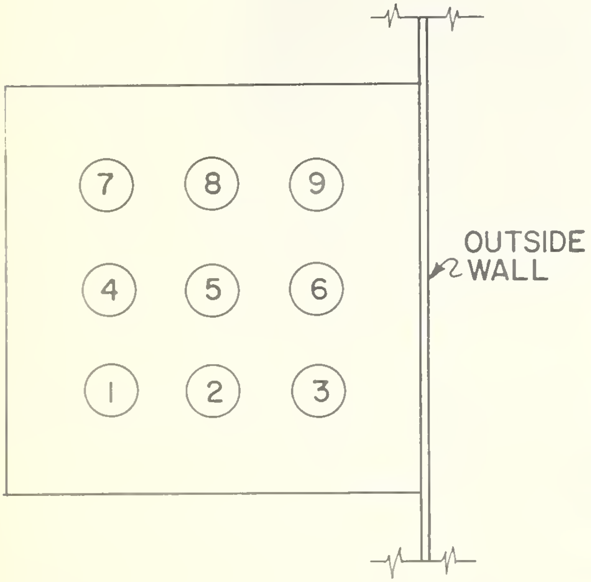

Figure 21.--Location of sampling areas (indicated by numbers) at the surface of experimental aerated and unaerated bulk storage bins, 9½ feet square by 24 feet deep.

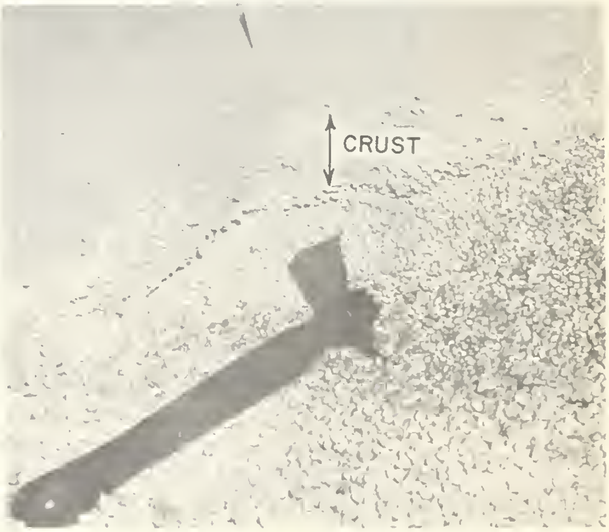

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Figure 22.--Surface layer of a bin of unaerated beans in which moisture has accumulated, mold developed, and a "crust" 6 to 8 inches thick formed.

Table 1.--Moisture content of pea bean samples taken from the upper 24 inches of an aerated bin of bulk stored pea beans, by sampling dates, 1957-58

Sampling area and depth of sample from surface 1/	Oct. 3	Oct. 18	Nov. 19	Dec. 12	Jan. 6	Feb. 27
	Percent	Percent	Percent	Percent	Percent	Percent
Area 1:						
Less than 6 inches	17.1	14.4	17.9	17.2	17.4	18.4
6 to 12 inches....	17.8	15.9	15.5	16.3	17.1	16.7
18 to 24 inches...	19.0	17.9	17.5	17.7	17.5	16.5
Area 2:						
Less than 6 inches	17.6	15.0	16.5	16.4	17.8	16.9
6 to 12 inches....	18.1	16.8	16.7	16.5	17.0	16.2
18 to 24 inches...	18.3	16.8	17.4	17.7	17.2	16.6
Area 3:						
Less than 6 inches	17.6	14.0	20.1	16.6	18.0	17.6
6 to 12 inches....	18.2	16.1	16.2	16.8	16.9	16.8
18 to 24 inches...	18.2	16.6	17.7	17.2	17.3	16.2
Area 4:						
Less than 6 inches	18.2	12.4	16.8	Lost	18.1	17.4
6 to 12 inches....	18.7	16.3	17.1	15.4	17.9	16.1
18 to 24 inches...	18.6	18.1	16.9	Lost	17.3	Lost
Area 5:						
Less than 6 inches	18.2	15.3	17.6	17.7	18.2	17.4
6 to 12 inches....	17.8	15.3	15.3	15.5	17.3	16.6
18 to 24 inches...	18.6	17.5	16.6	16.4	17.2	16.9
Area 6:						
Less than 6 inches	17.9	15.3	16.6	16.4	18.0	18.2
6 to 12 inches....	18.3	16.3	15.1	16.0	16.9	17.5
18 to 24 inches...	17.7	17.5	16.5	17.0	17.0	18.2
Area 7:						
Less than 6 inches	17.8	14.6	16.9	15.6	17.2	18.4
6 to 12 inches....	17.7	16.1	15.3	16.8	16.4	17.7
18 to 24 inches...	17.8	17.9	16.2	16.1	17.3	17.8
Area 8:						
Less than 6 inches	18.3	14.6	16.5	15.4	14.0	18.4
6 to 12 inches....	18.1	17.8	15.0	15.6	17.0	17.3
18 to 24 inches...	17.4	17.4	16.9	16.7	17.0	17.9
Area 9:						
Less than 6 inches	18.1	13.8	16.1	17.4	Lost	18.8
6 to 12 inches....	18.3	15.6	15.0	15.6	Lost	17.7
18 to 24 inches...	18.1	18.1	16.3	15.8	Lost	17.6

1/ See figure 21, page 34, for location of sampling areas.

Table 2.--Moisture content of pea bean samples taken from the upper 24 inches of an unaerated bin of bulk stored pea beans by sampling dates, 1957-58

Sampling area and depth of sample from surface 1/	Oct. 3	Oct. 18	Nov. 19	Dec. 12	Jan. 6
	Percent	Percent	Percent	Percent	Percent
Area 1:					
Less than 6 inches..	17.7	15.4	18.8	22.9	23.5
6 to 12 inches......	17.7	16.7	17.6	18.9	21.8
18 to 24 inches.....	17.7	16.6	16.9	18.7	18.3
Area 2:					
Less than 6 inches..	17.7	15.9	19.3	23.0	23.1
6 to 12 inches......	17.7	17.2	17.8	Lost	19.9
18 to 24 inches.....	17.7	15.7	17.0	17.8	17.9
Area 3:					
Less than 6 inches..	17.7	16.6	18.6	20.4	19.2
6 to 12 inches......	17.7	17.1	17.3	18.6	16.3
18 to 24 inches.....	17.7	17.0	16.2	17.8	17.9
Area 4:					
Less than 6 inches..	17.7	15.9	16.7	24.1	25.4
6 to 12 inches......	17.7	17.1	18.8	21.9	24.7
18 to 24 inches.....	17.7	17.0	18.7	19.4	Lost
Area 5:					
Less than 6 inches..	17.7	15.4	21.1	30.2	31.0
6 to 12 inches......	17.7	16.8	21.0	22.5	25.7
18 to 24 inches.....	17.7	17.2	19.3	18.9	19.0
Area 6:					
Less than 6 inches..	17.7	16.4	20.2	21.0	22.4
6 to 12 inches......	17.7	17.0	19.2	18.5	19.6
18 to 24 inches.....	17.7	16.7	18.0	17.8	17.7
Area 7:					
Less than 6 inches..	17.7	15.9	20.1	31.2	32.1
6 to 12 inches......	17.7	17.1	19.2	22.1	24.3
18 to 24 inches.....	17.7	16.2	18.5	18.4	18.5
Area 8:					
Less than 6 inches..	17.7	15.9	24.2	27.4	25.9
6 to 12 inches......	17.7	17.4	19.7	20.8	22.1
18 to 24 inches.....	17.7	16.9	17.9	18.2	18.6
Area 9:					
Less than 6 inches..	17.7	15.8	19.6	21.5	21.7
6 to 12 inches......	17.7	17.4	18.3	19.6	20.6
18 to 24 inches.....	17.7	16.8	17.2	18.1	18.3

1/ See figure 21, page 34, for location of sampling areas.

COST OF AERATING PEA BEANS

Examples of typical costs of aerating pea beans, including initial cost of equipment and installation and annual cost of ownership and operating are shown in table 3 for an upright storage and for a flat storage. The costs are based on information furnished by an aeration supply company and on 1959 price estimates at Lansing, Mich. No charge was listed for engineering services for designing these systems. These services are usually provided free of charge by equipment suppliers, except where the aeration system is complicated and special design work is necessary. Aeration in upright storages usually costs slightly less than in flat storages, as shown in this illustration.

Upright Storage

Initial costs of equipment and installation for an aeration system for three upright storages with flat bottoms, are shown below:

Initial Costs	Dollars
Fan and motor (18-inch propeller fan, direct-connected, to a totally enclosed 1½-horsepower motor)	350
Electrical installation (wiring from nearest service outlet, and wiring of motors, controls, etc.)	200
Supply pipes (necessary lengths of 12-inch, 18-inch, and 24-inch solid-wall pipe, plus elbows, cut-off, and connections)	250
	800
Ducts (22 feet--15 sections--of standard 36-inch diameter, half-round, perforated and corrugated)	180
Automatic controls (thermostats, humidistats, psychrometer, etc.), control box, and magnetic starter	125
	305
Total equipment and installation costs	1,105
	Cents
Initial cost per bushel of capacity	3.8

The three storages are to be connected together and aerated at 1/10 cfm per bushel with one fan and motor unit. Each storage is 16 feet in diameter and 60 feet high and has a capacity of 9,650 bushels (total capacity of three storages, approximately 29,000 bushels). (See figure 23.) Annual ownership and operating costs are shown in table 3.

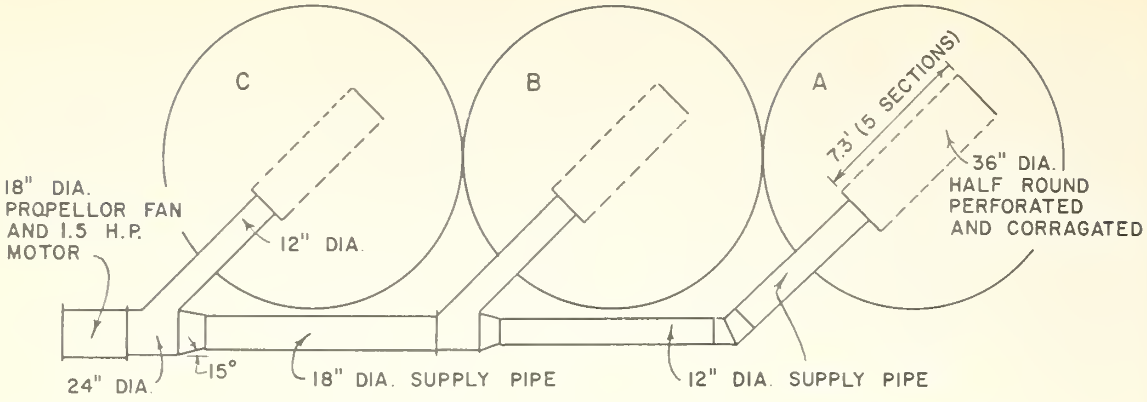
C
B
A
7.3' (5 SECTIONS)
36" DIA. HALF ROUND PERFORATED AND CORRAGATED
18" DIA. PROPELLOR FAN AND 1.5 H.P. MOTOR
12" DIA.
24" DIA.
15°
18" DIA. SUPPLY PIPE
12" DIA. SUPPLY PIPE

Figure 23.--Aeration system for three upright storages, each 16 feet in diameter and 60 feet high, flat bottoms.

Flat Storage

Equipment and installation costs of an aeration system for a flat storage for pea beans, with an airflow rate of 1/10 cfm per bushel, are shown below:

Initial costs	Dollars
Fan and motor (18-inch propeller fan, direct-connected to a totally enclosed 1½-horsepower motor)	350
Electrical installation (wiring from nearest service outlet, and wiring of motors, controls, etc.).	200
Supply pipes (necessary lengths of 18-inch diameter solid-wall pipe, plus elbows, cut-offs, and connections)	250
	800
Ducts (180 feet of standard 36-inch diameter, half-round perforated and corrugated)	1,450
Automatic controls (thermostats, humidistats, psychrometer, etc.), control box, and magnetic starter	125
	1,575
Total equipment and installation costs.	2,375
	Cents
Initial cost per bushel capacity.	4.9

The storage is 100 feet long by 50 feet wide, with a capacity of 48,000 bushels when beans are stored 12 feet deep. (See figure 24). Annual ownership and operation costs are shown in table 3.

Table 3.--Annual ownership and operation costs for aeration systems for pea beans in flat and upright storages (1/10 cfm per bushel), Michigan 1959

Kind of storage and equipment	Initial cost	Expected life	Annual costs							
			Ownership				Operating			
			Depreciation	Interest at 5 percent	Insurance and taxes at 4 percent	Total	Power and maintenance	Labor	Total	Per bushel
	Dollars	Years	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Cents
Flat storage: 1/										
Fan and motor, electrical installation and supply pipes	800	20	40.00	20.00	16.00	76.00	80	30	361.88	0.75
Aeration ducts and controls	1,575	15	105.00	39.38	31.50	175.88				
Upright storage: 2/										
Fan and motor, electrical installation and supply pipes	800	20	40.00	20.00	16.00	76.00	50	30	190.05	.66
Aeration ducts and controls	305	15	20.33	7.62	6.10	34.05				

1/ 100 by 50 feet; capacity 48,000 bushels; 2 floor ducts installed lengthwise of storage.
2/ Three silos, each 16 feet in diameter by 60 feet high; total capacity 29,000 bushels.

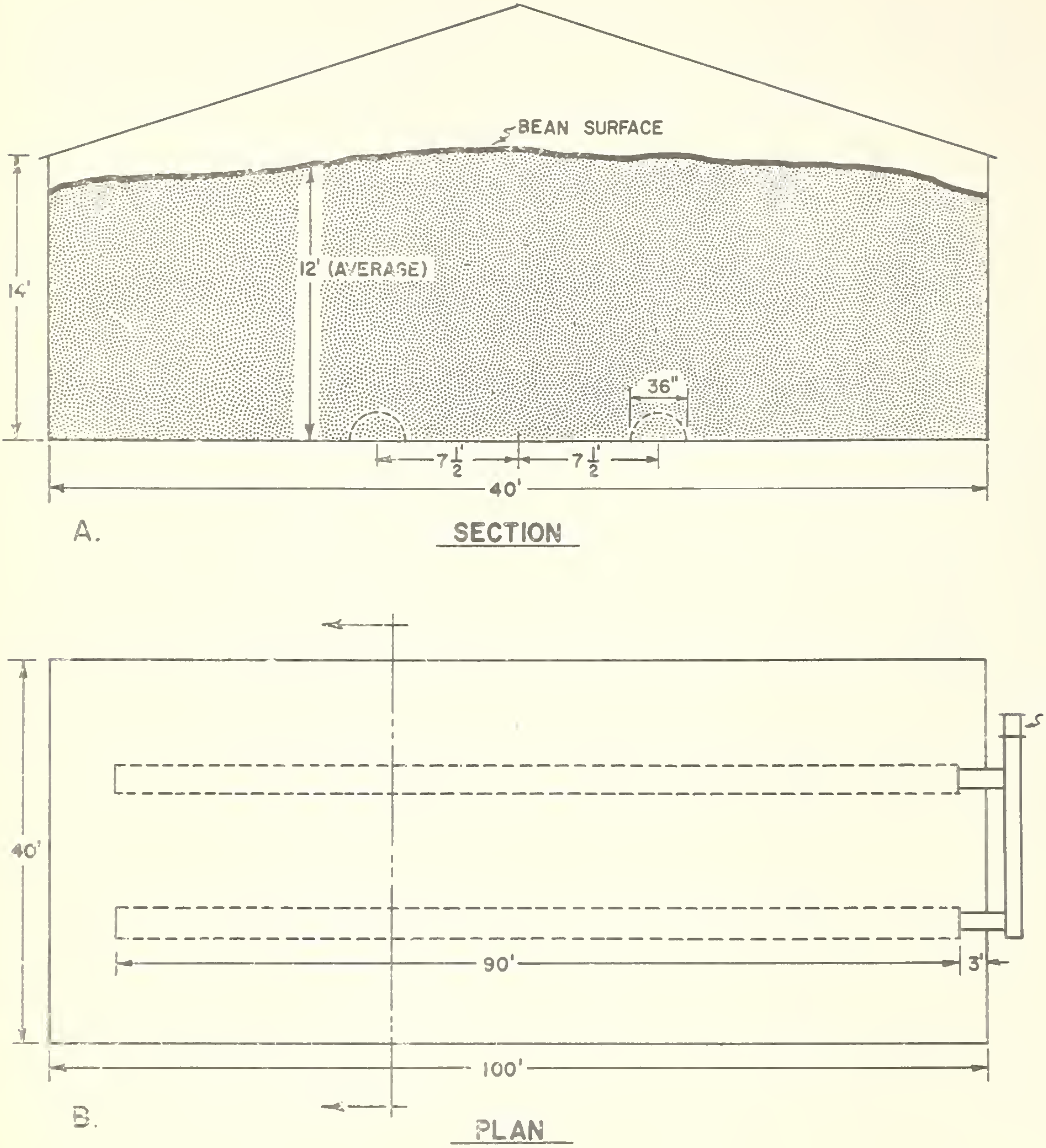

Figure 24.--Aeration system for flat storage, 40 feet by 100 feet, with beans 12 feet deep. (A) Cross section of storage, (B) floor plan.

APPENDIX

Information and Calculations for Designing an Aeration System for an Upright Storage

Description of storage: Three bins (silos) each 16 feet in diameter and 60 feet high and with flat bottoms, to be connected together and aerated with one fan and motor unit (fig. 22).

Storage capacity:

Volume: $(8 \text{ ft.})^2 \pi \times 60 \text{ ft.} = 12{,}060$ cu. ft.

Capacity: 12,060 cu. ft. x 0.8 (cu. ft. per bu.) = 9,648 bu.
(each storage)

Total storage capacity: 9,648 bu. x 3 = 28,944 bu. or about 29,000 bu.

Airflow rate and total air volume:

Airflow rate selected: 1/10 cfm per bu.

Total air volume (cfm): 9,648 bu. x 1/10 cfm per bu. = 965 cfm per silo
965 x 3 = 2,895 cfm for 3 silos

Determine duct requirements:

Surface area required for each silo: (see page 19)

$$\frac{965 \text{ cfm}}{30 \text{ fpm}} = 32.2 \text{ sq. ft.}$$

Selection of ducts:

Size and shape: Half-round, corrugated and perforated duct, 36 inches in diameter, with 4.72 sq. ft. of surface area per foot of length; cross sectional area = 3.5 sq. ft.

Velocity within duct - $\dfrac{965 \text{ cfm}}{3.5 \text{ sq. ft.}} = 276 \text{ fpm}$

Length of duct required - $\dfrac{32.2 \text{ sq. ft. surface area}}{4.72 \text{ sq. ft. per ft. of length}} = 6.82 \text{ feet}$

This duct usually is supplied in sections 17½ inches in length; therefore, use 5 sections of duct (7.3 ft.).

Note: A half-round, corrugated and perforated duct, 24 inches in diameter and 10 feet long, or a full-round, corrugated and perforated duct, 16 inches in diameter and 8 feet long also would be suitable.

Perforations in ducts - 3/32-inch diameter.

Note: These openings are suitable for wheat and corn as well as beans.

Strength of duct - Use 14-gage metal.

Determine supply pipe size: Supply pipes to be connected as shown in figure 23. Size is established by 2,500 fpm, maximum permissible velocity.

Size of supply pipe from silo A to silo B $\dfrac{965 \text{ cfm}}{2{,}500 \text{ fpm}} = 0.386 \text{ sq. ft.}$

therefore, 9-inch diameter duct is minimum size, 12-inch supply pipe selected.

Size of supply pipe from silo B to silo C $\dfrac{2 \times (965 \text{ cfm})}{2{,}500 \text{ fpm}} = 0.723 \text{ sq. ft.}$

therefore, 12-inch diameter supply pipe is minimum size, 15-inch supply pipe selected.

Size of supply pipe from silo C to fan $\frac{3 \times (965\text{ cfm})}{2{,}500\text{ fpm}} = 1.21$ sq. ft.

therefore, 15-inch diameter supply pipe is minimum size, 18-inch supply pipe selected.

Opening for air entrance to top of silo:

Select opening with cross sectional area twice that of supply pipe, or 0.772 sq. ft. (2 x 0.386 sq. ft.).

Provide continuous opening and protection from weather.

Assemble fan requirements:

Airflow rate: 1/10 cfm

Total air volume: 965 cfm per silo x 3 silos = 2,895 cfm

Determine power and static pressure requirements (from chart in figure 5):

Static pressure: 1.7 inches of water at 1/10 cfm per bushel through 60 feet of beans.

Estimated power required:

(From figure 5) 0.057 horsepower per 1,000 bushels is required.

Total horsepower = $0.057 \times \frac{29{,}000}{1{,}000} = 1.65$ horsepower (3 silos, 29,000 bu.)

Select motor: Consider a 1-3/4 horsepower motor. (Check with fan and motor supplier to determine if estimated power requirement is correct for the fan to be supplied). See page 12 for methods of adjusting horsepower requirements for efficiency.

Example of performance of one make of 7-blade, direct-connected 18-inch propeller fan:

Fan	Motor	Cfm at indicated static pressures					
		Inches					
rpm	hp	0.5	1.0	1-¼	1-½	1-3/4	2
3,450	1.5	5,000	4,500	4,200	3,800	3,400	2,700

Note: A smaller fan can be supplied for each of the three storages. Less supply pipe would be required but the total cost for fans generally would be higher.

Information and Calculations for Designing an Aeration System for a Flat Storage

Description of storage: A flat-type metal building 100 feet long and 50 feet wide with pea beans to be stored to a depth of 12 feet, (see fig. 24). One fan and motor are to be used for aerating the stored beans.

Storage capacity:

Floor area: 100 ft. x 50 ft. = 5,000 sq. ft.

Volume (cu. ft.): Floor area x depth; 5,000 sq. ft. x 12 = 60,000 cu. ft.

Capacity (bu.): Volume (cu. ft.) x 0.8; 60,000 x 0.8 = 48,000 bu.

Airflow rate and total air volume:

Airflow rate selected: 1/10 cfm per bu.

Total air volume (cfm): 48,000 bu. x 1/10 cfm per bu. = 4,800 cfm

Determine duct requirements:

Selection of ducts: Two floor ducts, each 90 feet long, to extend lengthwise through the storage and be spaced 15 feet apart (each duct 7½ feet from centerline of storage). Half-round, corrugated and perforated ducts selected.

Volume of air to be handled by each duct: $\frac{4{,}800 \text{ cfm}}{2 \text{ ducts}} = 2{,}400$ cfm per duct

Determination of size of duct (see p. 18)

$\frac{2{,}400 \text{ cfm}}{1{,}000 \text{ fpm}} = 2.4$ sq. ft. = minimum area.

Closest standard size of half-round duct is 36 inches in diameter (3.5 sq. ft. of cross sectional area).

Note: This type of duct can be obtained in 5 foot sections; therefore, 36 sections needed.

Checking duct size for adequate surface area (see p. 19)

$\frac{2{,}400 \text{ cfm per duct}}{20 \text{ fpm}} = 120$ sq. ft. of surface area required per duct.

$\frac{120 \text{ sq. ft.}}{90 \text{ ft. (length)}} = 1.3$ sq. ft. of surface area per ft. of length.

Half-round duct 36 inches in diameter has 4.7 sq. ft. of surface area per lineal foot; therefore, surface area is adequate in duct selected.

Determine supply pipe size: Supply pipes to be connected as shown in figure 24. Selected velocity in supply pipe = 1,500 fpm

Supply pipes to individual ducts: $\frac{2{,}400 \text{ cfm}}{1{,}500 \text{ fpm}} = 1.6$ sq. ft. minimum cross sectional area; therefore, 18-inch diameter pipe (area 1.7 sq. ft.) selected.

Supply pipes to both ducts: $\frac{4{,}800 \text{ cfm}}{1{,}500 \text{ fpm}} = 3.2$ sq. ft. minimum cross sectional area; therefore, 24-inch diameter pipe (area 3.1 sq. ft.) selected.

Assemble fan requirements:

Airflow rate: 1/10 cfm per bu.

Total air volume: 4,800 cfm

Static pressure: 0.6 inch of water at 1/10 cfm per bushel through 12 feet of pea beans.

Determine power and static pressure requirements (from chart in figure 5):

Static pressure: 0.6 inch of water at 1/10 cfm per bushel through 12 feet of pea beans.

Estimated power required: (From figure 5) 0.02 horsepower per 1,000 bushels is required. Total horsepower = $0.02 \times \frac{48{,}000 \text{ bu.}}{1{,}000} = 0.96$ horsepower

Select motor: Consider 1 or 1.5 horsepower motor (check with fan and motor supplier to determine if estimated horsepower is correct for the fan to be supplied. See page 12 for methods of adjusting horsepower requirements and fan efficiency.

See page 42 for example of performance of one make of 7-blade, direct connected, 18-inch propeller fan.

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